MASTER OF SCIENCE

The Hip and Lower Limb Movement Screen
Is it a valid tool to assess movement control in Royal Marines

Barbary, Stephen

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The Hip and Lower Limb Movement Screen: Is it a valid tool to assess movement control in Royal Marines

Stephen Barbary

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DEDICATION

Whilst this is not a life's-works it has certainly felt so at times and I am sure felt-by my Wife, Diane as well as my son, Keir and daughter, Lena. I remain very grateful for their support for the now, the past and the future.

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Of Dundee University, my supervisor Professor Rami Abboud, Dr Sadiq Nasir, Dr Weijie Wang and Dr Graham Arnold have provided colossal support in different ways.

Professor Rami Abboud provided his well-known intellectual direction as well as being instrumental in allowing and directing the building of a temporary on-site laboratory at Royal Marine Condor – this was not the agreed approach and plan but in the face of an early potential disaster dictated by the MOD Ethics committee disallowing the intended research on site at Dundee University, Professor Abboud calmly came to my rescue and agreed to build a 'lab' on-site. This project would simply not have gone ahead without his support which was well above-and-beyond any requirement. Sadly, Professor Abboud moved to pastures new and was unable to help with concluding work on my thesis but I hope his early insights and recommendations remain a part of this work.

Dr Weijie Wang and Dr Sadiq Nasir also tirelessly supported my many practical and academic hurdles and I am most grateful of their time and efforts.

Dr Graham Arnold has been my most immediate help and friend throughout this project and I owe my gratitude to him most of all – thank you.

Whilst this is not a life's-works it has certainly felt so at times and I am sure felt-by my Wife, Diane as well as my son, Keir and daughter, Lena. I remain very grateful for their support for the now, the past and the future.

DECLARATION

I hereby declare that this dissertation entitled “The Hip and Lower Limb Movement Screen: An Assessment of Validity with a Royal Marine Population” has been prepared by me under the direct guidance of Professor Abboud as part of my study for the award of Masters Degree at the University of Dundee, Dundee, Scotland.

I have not submitted this dissertation previously for the award of any degree or diploma at any other institution.

22/07/2022

Stephen Barbary

ABSTRACT

There are several movement screens used in military and sporting populations, utilised with the intention of providing information about potentially harmful movement patterns. There remains a lack of research into the validity of many of these, and in particular a lack of research into their validity with specific populations. The Hip and Lower Limb Movement Screen (HLLMS) is a relatively new tool, initially conceived to look at hip control in footballers and increasingly under review for use with the Ministry of Defence (MOD) for its ability to assess movement control with different military groups. To date there are no available studies that have looked at the suitability of the HLLMS for use with Royal Marine personnel.

This research paper aims to establish the suitability of the HLLMS for use by the MOD generally and with a Royal Marine Population in particular. Using 3D motion analysis as a means to measure the kinematics and kinetics at the hip, knee and pelvis this study evaluated the ability of the HLLMS to predict movement faults in several military-type complex movements. This study looked at how the HLLMS was able to predict movement faults with movements similar to military usage such as adopting a firing position, stepping down, landing from a height and these were tested under military standards of load carriage as well as before and after a standard Royal Marine 8mile load carriage test known as the combat fitness test (CFT).

An custom-built Motion Analysis laboratory was built at 45 Commando Royal Marines and 32 Royal Marines were recruited and took part in intensive data collection over a 2 week period. Each individual performed the HLLMS followed by the Military Functional Movements, each with and without a 55lb load carriage. Both of these were then repeated the following day after an 8mile speed march (Combat Fitness Test (CFT)) carrying standard Bergen (rucksack) and rifle. The primary analysis was to compare key component parts of the HLLMS against hip, knee and pelvis kinematics performing Military Functional Movements – each movement was performed and analysed with and without load as well as before and after a CFT. Analysis was also carried out comparing these kinematics to HLLMS total scores and sub scores. Finally, analysis was performed on changes to the HLLMS scores with and without load and after completing a CFT.

The findings in this paper revealed consistent trends with certain component parts of the HLLMS to predict deviations in knee and hip kinematics on single leg squat (p=0.09), loaded single leg squat (p=0.09) and loaded lunge (p=0.07). In addition the HLLMS, Small Knee Bend (SKB) showed an 86% correlation between hip adduction max excursion value on loaded lunge (p=0.006) and a 72% correlation for an increase in knee rotational ROM on unloaded lunge (p=0.017). The results of the analysis of the HLLMS scores with and without load did not reveal any significant difference but on comparison of the scores before and after a CFT revealed a significant difference (p=0.008).

The author concludes that the key HLLMS observational faults of Knee Dynamic Valgus and Pelvis Fail To Stay Level demonstrate sufficient merit to recommend further use and research but suggests that the method of evaluating these complex movements may need to be reconsidered. The author also concludes that the clinical use of the HLLMS Small Knee Bend sub-scale in assessing movement faults in Royal Marines has significant value in particular in is ability to predict movement faults that occur whilst carrying load. Finally whilst further analysis is necessary the HLLMS' ability to measure changes in performance after a CFT may also prove beneficial in improving our understanding of the effect this arduous activity has on movement control and how intervention may be best placed to limit these changes and reduce injury risk.

CHAPTER 1

1.1 INTRODUCTION

1.2 MILITARY CONTEXT AND ROYAL MARINES

The nature of military training and service has long been associated with increased risk of injury with infantry personnel being at greater risk than other services (Andersen et al, 2016). Musculoskeletal injury (MSKI) is a significant cause of medical attrition in male and female Service personnel. In 2013/14, 2,714 tri-service personnel were discharged due to Musculoskeletal Injury (MOD 2014) in the Army alone, it has been conservatively estimated that MSKI could cost the MOD in excess of £1.2bn over the next 15 years (2016-2021), where this figure does not include associated medical care costs (Management Consultancy Services 2016).

Serving Royal Marine personnel are at particularly high risk of MSKI throughout their careers due to their particularly arduous occupational roles, often in extremely hazardous and austere environments. Personnel need to maintain high levels of strength and aerobic fitness whilst in deployment readiness, this and the physical and psychological stresses on deployment contribute to high levels of injury risk throughout their career (Fallowfield 2014).

To date, whilst there are some published studies looking at injury factors in Royal Marines, research into this population remains very limited. Stoneham et al (1991) examined hip stress fractures in Royal Marines, House et al (2013) looked at the incidence of overuse injuries in Royal Marines and Nunns et al (2012) measured the effect of footwear in relation to stress fractures in Royal Marines. The body of knowledge however that can be drawn upon relating to Injury Risk in Royal Marine personnel remains stark and this research thesis therefore aims to provide much needed data in this area.

This research paper focuses on lower limb movements because the risk associated with lower limb injuries is particularly high - in UK infantry populations, injury rates pre-deployment have been reported to be as high at 60% (Wilkinson 2011) with lower limb MSK injuries being widely reported as the most common cause of all of these (Reynolds 1999).The cost of managing these musculoskeletal problems both short and long term in the hip and lower limb is rising and is creating a drive for more preventative forms of intervention (Roos 2016).

1.2.1 Movement Control as a Risk Factor for Injury

Musculoskeletal Injury prevention remains one of the top research objectives for Defence Medical Research in the UK and key to this is identifying what are the main risk factors. Extrinsic factors such as load carriage and high volumes of training are often cited as major causative factors (Kaufman et al, 2000) with loads greater than 24 kg or 33% of body mass having a strong predictor of lower Limb injury (Haisman 1988, Majumdar et al 2010). Load carriage will also influence changes in movement patterns which in turn are associated with increased injury risk (Rice 2012).

Whilst a degree of injury risk may arguably be mitigated for by modifying training volume in a way to maximise adaptation and minimise injury - especially in recruits, it may be argued that in serving personnel, these risk factors are unavoidable and simply the consequence of military service. There have been identified other so called ‘intrinsic’ risk factors such as fitness, low or high body mass index or flexibility etc amongst others and these have been reported as being linked to increased injury risk both in recruits and serving ranks (Jones et al 1993). A recent prospective study of injury risk factors in British army recruits, for example, found low fitness, low body mass and prior injury to significantly increase the risk of further injury (Robinson et al, 2016). Other factors such as bone geometry, height and other anthropometric variations may also increase risk of injury but such factors remain fixed for the individual (Finestone et al 2008)

A recent systematic review of the most effective injury prevention strategies for the UK military indeed highlighted lower physical fitness and inappropriate training volumes as two of the main risk factors to injury (Wardle et al 2017). In addition, the authors' final recommendations for strategies to reduce injury risk included conditioning programs that focused not only on strength and endurance training but also placed great emphasis on balance, agility and neuromuscular training.

This focus towards neuromuscular control was discussed in length by Comerford et al (2007) who purported the need for "A New Perspective on Risk Assessment" – with a focus on the assessment and ultimately the retraining of movement control in complex functional tasks such as the Small knee bend (SKB), step down, lunging etc. Movement patterns such as jumping, landing, lunging etc require processing of complex sensory and motor systems in order to maintain joint position and stability, the loss of which can cause excessive strain on various musculoskeletal systems leading to structural failure (Huston 2001). Asymmetry of movement patterns has also been linked with injury to one side of the body with muscle strength or flexibility imbalances, movement control or passive ROM often being cited as the cause of injury (Zifchock 2006). This loss of neuromuscular control leads to changes in movement patterns which have been shown to be a potential factor in MSKI. Maintaining the ability to effectively move within the limits of the structure, and the mobility of the joints, could therefore reduce MSKI risk (Lisman 2013).

There has been a good level of research linking poor movement control in people with low back pain (Hodges and Moseley 2003). More recently movement control in relation to lower limb injuries is a growing area of research. Already there are demonstrated links between overuse as well as acute injuries for problems related to the ACL, Patellofemoral joint and the hip joint (Austin 2008, Hewett 2005, Bisseling 2006).

Paterno et al (2010) used 3-dimensional motion analysis and Biodex stability system to measure movement control and found that deficits in postural stability and altered neuromuscular control at the hip and knee proved strong predictors of future knee injury. The potential cause of increased injury risk includes factors such as genu varum and valgus, external rotation of the lower limb being linked with increased risk of developing stress fractures both in civilian and military populations (Taunton at al 2002, Ross et al 2002). Recent research based at the Commando Training Centre, UK on Royal Marine recruits found that subjects who scored poorly on movement control tasks of single leg squat and jumping and landing tasks proved significantly more likely to go on to develop low limb overuse injuries (Nelstrop et al 2017).

Sport as well as military organisations are focusing on movement control in injury prevention strategies. The FIFA 11+ program is showing promising results in reducing injury rates with a focus on combining dynamic type warm up exercises with different levels of agility, proprioception and neuromuscular balance training (Silvers-Granelli et al 2015).

1.2.2 Review of Movement Control Screens

A recent review of several systematic reviews by a US Joint Service Injury Prevention Working Group concluded that the use of multiaxial, neuromuscular and proprioceptive, movement control training had a good body of evidence to support its use in injury prevention for military groups (Bullock et al 2010). In addition, they recommended the importance of tailor-made programs for certain individuals and that Allied Health Professionals should be utilized more for such assessments and screening.

Measuring of GRF and other complex kinematic and kinetic factors requires expensive equipment and a high level of expertise that is not available to most health-care professionals (Paterno 2010).

A recent systematic review by Whittaker et al (2017) of the literature for studies involved in assessing movement quality and their ability to screen for future injury concluded that further research was required in this area. This research thesis therefore aims to provide further data in this area by validating a screening tool and its' validity with a Royal Marine population for which to date, no such studies have been conducted.

Movement Screening tests in the literature include both qualitative and quantitative, or Physical Performance Tests (PPTs) tests. There remains limited evidence as to the validity of PPTs such as 1-legged hop for distance, vertical jump, shuttle run, 6-m timed hop tests' ability to predict increased injury risk. Volger et al (2017) in a systematic review looked at 16 PPTs there was poor evidence of validation of these tests for injury prediction with perhaps the exception of The Star Excursion Balance Test (SEBT) which has shown some ability to identify athletes with previous ankle (Pourkazemi 2016).

Doherty et al (2015) also looked at the SEBT in relation to reduced performance post-acute ankle sprain and in terms of kinematic changes more proximally and Delahunt et al (2013) looked at changes in the SEBT in athletes post knee (ACL) injury and found interestingly that as well as reductions on all aspects of the SEBT, these subjects also showed consistently increased hip adduction with reduced knee and hip flexion. In summary the literature suggests that PPTs have limited standardization and validated properties taken as a group.

Movement Quality Tests involve single movement such as a single leg squat , step down etc or a battery of tests such as seen in The Functional Movement Scale (FMS) or the Landing Error Scoring System (LESS). Different Movement Quality Tests (MQTs) define, somewhat arbitrarily, different movements as 'faults', with the trunk, pelvis , femur, knee, tibia foot and ankle often observed for deviations from a starting or neutral position on sagittal, transverse and frontal planes. Some studies looking at particular pathologies such as patellofemoral joint problems may place, for example, greater weight on certain movements faults in particular planes and therefore these Movement Quality Tests may have a much greater relevance to injury than the PPTs described above (Powers 2003).

As introduced above, there are a number of Movement Quality Screens available for clinical and research purposes. Whilst the scope of this paper does not seek to discuss every available such tool, the most commonly used, the ones most obviously similar to the one adopted and the reasons behind the authors choice will be discussed in more detail.

The Functional Movement Scale (FMS), for example, includes three lower limb movements: squat, in-line lunge, hurdle step. These are assessed on the performer's ability to maintain trunk and LL alignment on the sagittal and frontal planes. Whilst this paper has shown excellent Inter-rater reliability (Minick et al 2012) and shown to have some value in predicting injury in professional American football players (Kiesel et al 2007) the FMS alone had limited ability in predicting injury in military personnel (Lisman et al 2013).

The LESS is a more dynamic movement screen used initially for jumping sports and focuses on the feet and body alignment on landing following a vertical jump. The LESS and the Drop Jump Test (DJT) whilst scored and executed slightly differently are very closely related and therefore discussed together. Assessment of both of these in real time and with video analysis have both been well validated (Brown 2014). The LESS has been used in both sporting and military populations (Beutrel et al 2009)and has shown to be able to reliably identify high-risk movement patterns associated with increased risk of an Anterior Cruciate Ligament Injury (Padua et al 2009). Several authors however have echoed the importance of identifying movement faults specific to certain tasks (Ludewig et al 2013) and the need therefore to identify specific movement impairments for the target group (Teyhen et al 2014). Both the LESS and DJT However have notably strong face validity to performance sports that involve hopping and jumping but may not be as pertinent to movements typical in a military environment.

The Hip and Lower Limb Movement Screening tool developed by Southampton University comprises of seven tests: a small knee bend (SKB); SKB with trunk rotation; deep squat; standing and sitting hip flexion to 100degrees and side lying hip abduction with the leg laterally then medially rotated. With each of the movements the performer is marked by the observer on several movement faults such as the Pelvis Failing to Stay Level, or the knee moving into a valgus position. Each of the faults is measured on a dichotomous scale – i.e. Is there a fault? - Yes or No.

It should be noted that the HLLMS has a combination of arguably everyday movements: squat, SKB but also some movement patterns that would be completely new to many people. The rationale is however that everybody should have the ability to perform movements that they are not habitually used to doing and that their ability to do so is a good measure of their internal control systems (Comeford 2007) and it is this which the screen seeks to measure. The use of whole body tasks such as the HLLMS which assess coordination, ROM and proprioception of several joints simultaneously are considered a far better measure than traditional tests of single joint ROM or strength (Kiesel et al 2011) for evaluating movement control.

The HLLMS was conceived initially for use with a sporting population and as such may have limited value with a military population and with military movement patterns. Many of the movement patterns however such as the small knee bend, squat and small knee bend with rotation are very common to daily movement of military personnel. In addition, the fact that this screen was performed with military load and rifle carriage the face validity of this method is arguably much greater validity to this population. In addition, volunteer subjects also were measured before and after an 8 mile load carriage speed march, known as a Royal Marine Combat Fitness Test. Whilst there was no attempt to measure the level of fatigue following this task the decision to gather data before and after this activity provides additional meaning to the results' validity to this specific population which performs such physical tasks on a regular basis.

1.2.3 Predictive Criterion Validity

Validity is the extent to which an instrument or in this case a visual rating tool is able to measure what it is intended to measure. Validity can be divided into face, content and criterion validity (Laukkennen 1993). Comparing the visual rating from the HLLMS against a chosen Standard would be classed as measuring the Criterion Validity of the rating scale.

Concurrent Criterion validity would have the Standard, measure the efficacy at the same time, i.e. concurrent. Research in this area has recently been completed at Southampton University looking at the concurrent validity of the HLLMS (Wilson 2019) as well as its' reliability (Booysen et al 2019). This study therefore aims to look at a different aspect of validity namely the predictive validity. It is of note and that Wilson et al (2019) found limited validity in certain aspects of the HLLMS and this finding is somewhat inconsistent with the findings of this thesis and is discussed later in Chapter 6 considerable room for discussion around the collective findings.

This paper therefore aims to test the predictive criterion validity of against an agreed Standard. What this Standard is however is itself a question for debate. The author chose in this study to use Plug In Gait Motion Analysis and a pre-defined set of movements as the standard to which the HLLMS is measured. Both these aspects have certain limitations and assumptions.

1.2.4 Limitations of the Standard

3D Motional Analysis which has been suggested to be the Gold Standard for measuring kinematics and kinetics (Maclachlan et al, 2015) has many different models, each with their own limitations. This research paper used the Plug In Gait model of Gait Analysis due to the available hardware and expertise at the Institute of Motion Analysis and Research at The University of Dundee. Potential errors of this system are widely reported in the literature and include soft tissue artefact (movement of markers due to soft tissue movement), marker displacement, marker drop out as well as problems with the model's inherent ability to accurately estimate joint centres(Taylor et al 2005). These limitations are discussed further in Chapter 3 and how certain conclusions around this paper's results need to be taken with some caution.

The other limitation of the Standard pertains to the agreed upon movement faults which are primarily related to certain known mechanisms of injury. The limitations to the scope of this paper due to these assumptions and the boundaries that result to the final conclusions are discussed in the Chapter 3 on methodology.

In summary therefore, this research study provides a much needed data set for a highly specialised population of elite soldiers around the questions of injury risk – a field denoted as high priority to the Ministry of Defence. A detailed Movement Screen

known to have strong inter-rater reliability and utility in sporting populations was tested with the addition of military load carriage to provide some unique analysis of movement faults both under load and following an 8 mile military speed march.

CHAPTER 2

2.1 LOWER LIMB INJURY MOVEMENT FAULTS AND THE HLLMS.

One major underlying assumption to this work is that certain movement patterns are 'better' than others or that certain movements are considered detrimental. This assumption is based on our observations of the biomechanics of injuries in the lower limb and are therefore discussed and evaluated here. This study chose to use the Hip and Lower Limb Movement Screen (HLLMS) to measure these movement patterns partly for reasons outlined in Chapter 1 but also because of the fact that this tool has strong face validity for this purpose. Explained another way, the movements described below associated with certain injuries relate very closely with the movement patterns that the HLLMS was designed to detect. The Hip and Low Limb Movement Screen (HLLMS) developed by Botha et al (2013) was specifically designed to focus on assessing multiple-joint alignment with a view to screening for movement faults that could lead to increased risk of injury or osteoarthritis (OA) (Wilson et al 2018). The author recognises that there is limited evidence however around the HLLMS's ability to predict movement faults that may lead to injury due to the small number of studies, to date, that have been conducted on the HLLMS. This body of work therefore aims to provide much needed objective analysis.

2.1.1 Biomechanics of Common Lower Limb Injuries

This section outlines some of mechanisms associated with the injuries this cohort most commonly involved in and concludes with a discussion of the face validity of this tool. It is important to recognise that the scope of this work is limited by the amount and quality of evidence that exists around these and other injuries. A brief description and review of the literature associated with the most common lower limb injures is discussed as this forms both the basis and the limitations of this thesis.

All musculoskeletal injuries can be divided into those that happen due to a single event, caused by trauma and those that happen over a period of time. We will refer to the latter as an Overuse Injury - these are considered to result from an accumulation of load, overtime, when the musculoskeletal systems exceed their load of tolerance (Matilla et al 2011). Single event, traumatic injuries may be further divided into contact and non-contact injuries. A contact injury is where, for example, a person collides with something causing an external force to act on a MSK structure causing damage. A non-contact injury would refer to a sudden injury in the absence of an external force such as someone twisting severely on a fixed foot – both of these are relevant to this thesis if certain joint kinematics can be evidenced as influencing such injuries.

Research into links between hip dysfunction and knee injuries is not new – Niemuth et al (2005) and Leetun (2004) looked at both hip and core control in overuse injuries in runners and other athletes. The predominant mechanism found was that an increased adduction and internal rotation at the hip results in a valgus and internal rotation torque moment at the knee. The logical conclusion being that the restraining structures at the knee such as the medial collateral ligaments, the anterior cruciate ligaments and the menisci for example would be subject to force and moment changes. Figure 2.1 illustrates how the effects of the changes in pelvis position on the frontal plane can affect forces and moments at the knee.

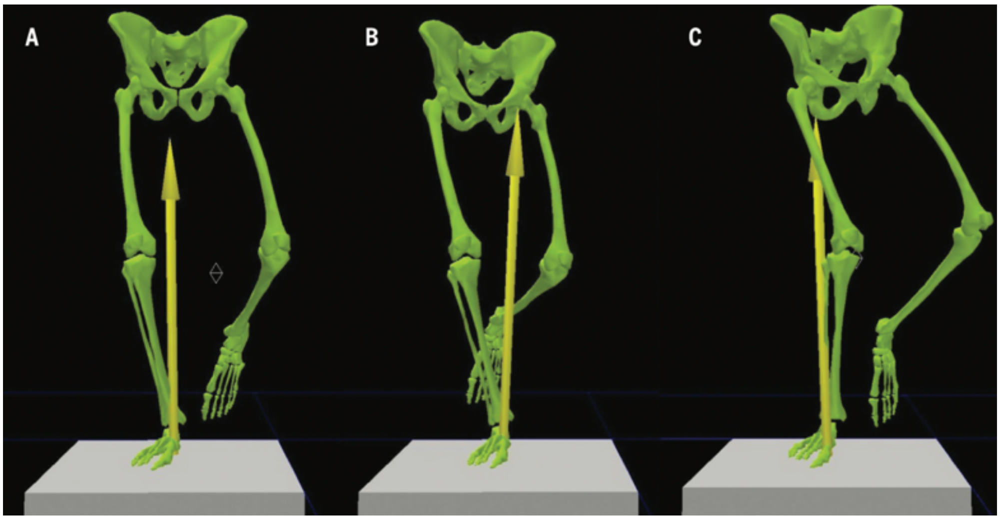


Figure 2-1 Knee displacement secondary to hip adduction and pelvis drop, modified from Niemuth et al (2005)

In A (figure 2.1), in single leg stance, the centre of gravity of the body is passing medially to the knee joint creating a moment at the knee which compresses the medial (inside) of the knee whilst tensioning the lateral (outside) knee. In position B (figure 2.1), where the hip drops slightly on one side, this moment increases further due to the change in position. In position C (figure 2.1), the line of force is changed and the knee is now under a tensile force laterally and under compression medially. Powers 2010 et al (2010) argues that such movements will increase the likelihood for example of overload to the ligaments placed under tension and bony structures placed in compression.

Femoro-acetabular impingement (FAI) is often associated with structural abnormalities in the shape of the head of the femur, the acetabular socket or both (Khan 2016). However as with many MSK problems the evidence suggests that a symptomatic problem is not simply due to a structural finding and that a combination of structure and biomechanics of movement are more pertinent to causing a symptomatic problem (Frank et al 2015).

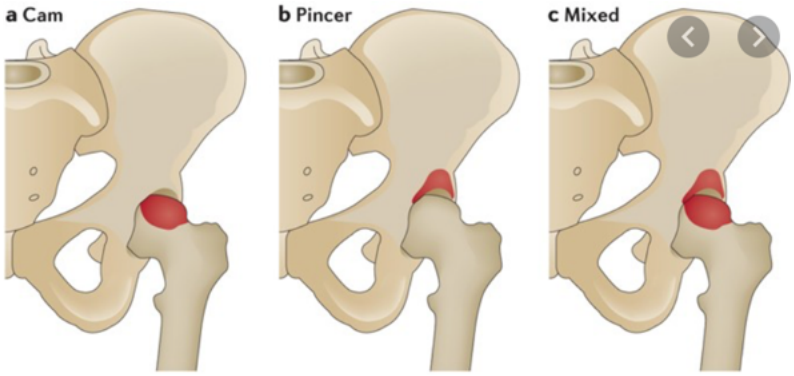


Figure 2-2 Anatomy of Femoral Acetabular Impingement, modified from www.nature.com/articles/rrheum.201617.

Repetitive impingement is the basis of pain in FAI and several authors have shown a link between this and reduced hip internal rotation (Kuhlman et al 2009). This thesis is interested in movement control at the knee, hip and pelvis and Booysen et al (2017) amongst others have hypothesised that the inability to control movements and the hip and pelvis may contribute to FAI as well as injuries more distally. Indeed, Diamond et al (2017, 2018) was able to demonstrate that a reduction in control between the hip and pelvis was a common feature in people with FAI related pain with movement patterns such as hip hitching and trunk lean contributing to positions of hip impingement and ongoing symptoms even after surgery. The research evidence in this area, particularly in young sporting populations remains limited at this time and the aim of this thesis is to provide data around hip and pelvis control in a very specialised population. In doing so, as the body of evidence around movement control and FAI strengthens this thesis' findings may then be extrapolated further.

Anterior cruciate ligament injury is generally considered to be caused by a sudden event and may be classed as either a contact or non-contact injury. Non-contact ACL injuries only will be discussed here as they make up 70% of all ACL injuries and are considered to have a significant link with movement control (McLean et al 2004).

Anterior Cruciate Ligament (ACL) Injuries of The Knee remains one of the more extensively researched areas linking knee injury to certain biomechanical movement patterns. In an early cadaveric study, Seering et al (1980) showed that moment forces of as little as 120-180 NM valgus torque or 35-80NM rotational torque were sufficient to damage the ACL. Koga et al used this proposed value in their own model to examine the various forces (anterior/posterior, valgus/varus, internal/external) that occur at the knee joint following a cutting movement. These early papers as well as observation studies of mechanisms of injury have have led to several authors' examining the links between certain movements and injury to the ACL(Quatman and Hewitt 2009).

Females are known to be 5-7 times more likely than males to incur a non-contact ACL injury and it is this fact that have allowed researchers an empirical window into some of its' peculiarities. In particular, many researchers have focused on the biomechanical differences between males and females with a view to explaining what aspects of our biomechanics may increase risk of injury in all sexes.

Similar to the movement fault illustrated in Figure 2.1, Koga et al (2010) and others, have proposed a common mechanism for non-contact ACL injuries in women as a combination of valgus loading and internal rotation. Some debate about the mechanism of these injuries still remains ongoing but certainly for non-contact ACL injuries the valgus overload in females and an excessive internal rotation moment in males are key features of the injury.

The reasons that individuals demonstrate these joint malalignments is still under debate. Pollard et al (2010) found that females relied less on the hip extensors to absorb landing forces and postulated that this was a reason for the commonly seen reduced knee flexion also associated with the injury was commonly reported. This finding, directed researchers to look for links between hip strength and ACL injury incidence but several authors failed to find convincing correlations (Sigward 2008). This line of questioning that has led to the ever-widening discussion around motor control or Neuromuscular Control (NMC) an underlying theme to this paper. Koga et al 2011 was even able to show that changes in NMC patterns were able to bring about valgus and rotational forces sufficient to rupture the ACL.

2.1.2 Neuromuscular Control and Lower Limb (LL) Injury

NMC refers to the body's ability to control joints, muscles and movement. In the ACL injury and in particular in looking for ways to help prevent it, it may not be so much about simply the position of joints but a combination of factors. The ability to control the valgus / varus and internal rotation forces in different positions of knee flexion, either due to muscle control strategies or anatomical peculiarities at these angles may be key. Not just in isolation but about how the dynamic systems are able to control various forces, how these systems are affected by joint position, co-contraction and muscle activation patterns.

Patellofemoral pain syndrome (PFPS) is a commonly used term to describe one of several conditions known collectively as anterior knee pain and one which has a high prevalence within general practice, orthopaedic and sports medicine (Barton CJ, et al 2015). Incidence rates of between 25% and 43% have been described in sports medicine and basic military training (Lankhorst et al 2012).Evidence associated with hip, knee and ankle alignment and anterior knee pain has long been postulated (Livingston et al 1999). Several authors have studied foot posture in relation to this (Levinger and Gilleard 2007) but the literature has failed to show any convincing links between these, both on civilian (Powers et al) and military populations (Hetsroni et al 2006). There is growing interest in the role of hip control with peak hip adduction and rotation and associated poor sagittal and frontal knee control have all been prospectively associated with increased risk of AKP (Noehren et al 2013).Poor control of the proximal chain (The Hip Joint and pelvis) possible secondary to reduced strength or control of associated muscles and movement systems has been associated with PFPS – reduction in hip abduction, hip external rotation strength were reported by several authors (Lack et al 2015, Cowan et al 2009 and Priva et al 2005).

Meniscal tears are usually the result of a sudden rotational torque on a slightly flexed knee (Bernstein 2010). Whilst sudden rotational movements that result in injury may always be a feature in sporting pursuits, coaches and physiotherapists would argue that good biomechanics or good technique or neuromuscular control remain key to minimising such injuries.

The UK Defence Medical Rehabilitation Guidelines now group all leg pain related to overuse under the term Exercise Induced Leg Pain (EILP). This refers to pain between the joints of the knee and ankles and includes patho-mechanisms of stress fractures of the leg, medial tibial stress syndrome (MTSS), compartment syndrome and other soft tissue injuries. Lachniet et al (2018) looked at possible biomechanical 'errors' in runners who had or previously had Sx consistent with signs of bony stress response such as MTSS showing increased hip IR, hip drop and reduced knee flexion as potential biomechanical factors. As with hip impingement, the biomechanical causes of EILP have not been clearly defined due to a lack of sufficient research. Pohl (2006) and Milner (2008) amongst others found increased peak hip adduction to be included in the possible factors. Increased step length and subsequent over-stride (where the contacting foot lands ahead of the body's CoM) seem also to be key factors. A discussion on running biomechanics is beyond the scope of this discussion but until hip and knee kinematics are ruled out in these conditions the ability to measure and quantify movement control remain clinically pertinent.

Having introduced the basis to this thesis – that certain biomechanical movement patterns are associated with injury it is useful to compare the movement faults described in the HLLMS.

2.2 OVEMENT FAULTS IN THE HLLMS

The most commonly observed movement faults in the HLLMS are:

1. Loss of trunk control in standing, sitting – forward lean, backward lean, side lean

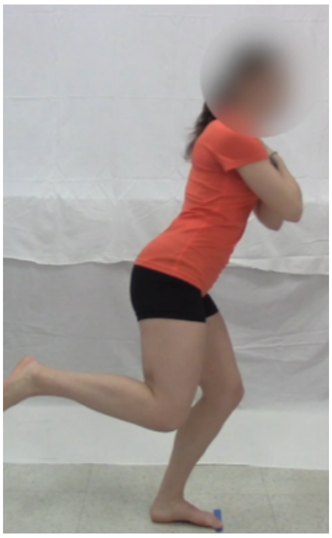


Figure 2-3 Loss of Trunk Control in Standing

2. Loss of pelvis control in standing, sitting and side lying: Hip drop, pelvic tilt

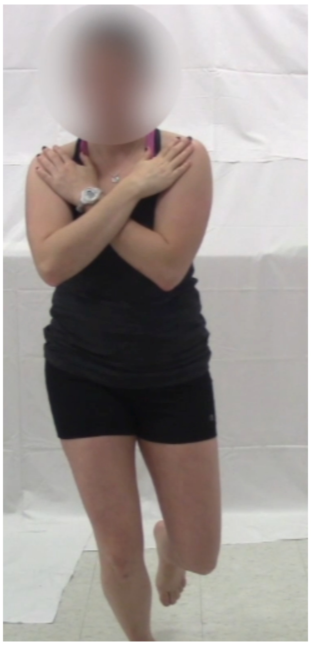


Figure 2-4 Pelvis Fail to Stay Level

3. Loss of hip and knee control in standing: knee valgus,

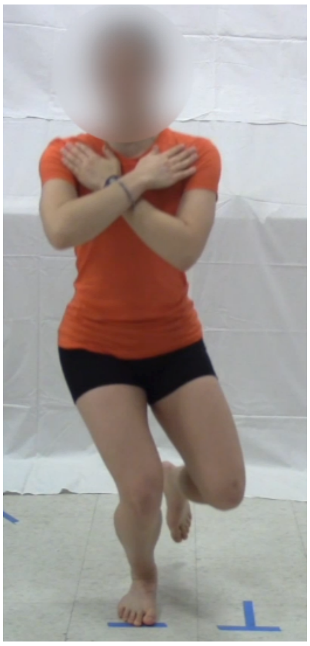


Figure 2-5 Increase in Dynamic Valgus (knee falls in)

4. Unable to move hip without also moving pelvis.

Figure 2-6 Pelvis tilts Backwards as Hip Flexes. Not able to move independently

The author recognises that there is a limited research basis behind the use of the HLLMS to detect injury but the movement patterns seen in certain injuries and the movement faults looking to be observed in the HLLMS have clear similarities or face validity. In particular, the single leg squat is considered a crucial movement pattern requiring assessment, something lacking in the FMS (Bailey et al 2009). The Single leg squat, or small knee bend as used in the HLLMS has shown to have good validity in recognising hip dysfunction (Kivlan and Martin 2012).

It is important to note that a recent, not fully published PhD thesis (Wilson et al 2019) looking at the reliability and validity of the HLLMS concluded that in terms of criterion validity only 50% of the observational rating criteria were shown to have acceptable validity and differences between sides were significant. Whilst some of the HLLMS observational rating criteria have subsequently been altered as a result of these finding this thesis used the same original rating criteria. This important finding requires careful consideration when discussing the results of this thesis as there are clearly potential limitations to the validity of this tool. To date though, other than the work by Wilson et al (2019) no other validity studies have been made of the HLLMS and the assumed basis for its use remains as described above.

CHAPTER 3

3.1 METHODOLOGY, DESIGN AND DATA COLLECTION

As noted in Chapter 1 the overall aim of this work is to investigate the validity of the Hip and Lower Limb Movement Screen. The method or chosen standard for assessing this in this study is to use 3D motion analysis. This chapter presents a short discussion as to the rationale and limitations of this method, In addition the specific model chosen for this method was the Plug In Gait System and therefore a brief discussion of the benefits and limitations of this model are also discussed here. Finally this chapter provides a description and account of the work done during this investigation in building an on-site laboratory at the 45 Commando Royal Marines Base.

3.1.1 3D Motion Analysis as the measure of observational movements

Nae et al (2017) conducted a systematic review of observational screening of knee-medial-to-foot position (KMFP) against 2D and 3D kinematics in asymptomatic populations concluding that these were both valid and reliable. They also concluded however that there was insufficient evidence to draw the same conclusions for postural errors involving other segments. Whatman et al (2017) reviewed 39 papers that looked at the validity and reliability or clinical assessment of lower extremity dynamic alignment with different movements and concluded that rating knee position of the single leg squat, single small knee bend and drop jump tests proved to have the most valid utility. Differences in 2D and 3D kinematics for knee valgus on single leg squat were found by Ageberger et al (2010) who concluded that there was a lack of validity for the 3D data whilst the 2D results showed excellent validity. One apparent explanation for this is that the observed knee valgus fault may actually be a combination of hip adduction and both hip and knee rotation or a combination of these but any one in isolation was not able to show significant correlations. This issue is discussed later in Chapter 6.

Overall, the evidence therefore suggests that 3D kinematic analysis of the knee postural alignement during the small knee bend test as investigated in this paper has good utility but that there may be issues around an observed 2 dimensional movement and the 3D multi-joint reality.

Whilst some authors have referred to 3D motion analysis as the "Gold Standard" for measuring movement (Maclachlan et al 2015) it is also important to consider the limitations and errors associated with 3D motion analysis and that there are several different systems and models each with their own limitations and 'approximations'. The model used in this investigation was Vicon's Plug In Gait model, a short evaluation follows.

3.1.2 Plug In Gait

The Plug In Gait (PiG) is one of the most commonly adopted of the Conventional Gait biomechanical models (CGMs) adopted in the 1980s and has been validated by several authors (Kabada et al 1990, Davis et al 1991). There are several limitations of this model including the accuracy of estimating the hip and knee joint centres (Peters et al 2012,) defining the coronal plane of the femur, over simplistic foot modelling (Carson et al 2001)and issues around inadequate compensation for the movement of soft tissues, known as soft tissue artefact. The group of models considered most effective in reducing the limitations of the CGMs are those that adopt Six Degrees of Freedom (6DoF) using rigid clusters and these are generally considered to provide a more accurate definition of hip and knee joint centres (Barre et al 2013). This investigation trialled the use of the Optimal Common Shape Technique (OCST) and the SARA and SCoRE methods for determining knee and hip joint centres. Ultimately however the author reverted to the PiG model as it was possible as a single researcher with minimal experience to set-up and extract the required information with minimal need of specialised staff support. The relative conceptual simplicity of the PiG system, the very well established reliability

(McGinley et al 2009), and the ease of set-up and data extraction, including kinetic data made for a ease of use. The fact that this model relies on estimated joint rotations and only 3DoF mean that results of knee and hip valgus and rotations need to be reported with some caution as Standard Errors of greater than 5 degrees have been reported (McGinley et al 2009).

3.1.3 Ethical Considerations in Medical Research

Full ethical approval was obtained from the Ministry of Defence Research Ethics Committee on 29/6/18. Reference: 865/MODREC/18 Appendix A

Full ethical approval was obtained from The University of Dundee, School of Medicine on 03/05/18. Reference: SMED REC 026/18 Appendix B

3.1.4 Study Overview and Design

As stated above, this investigation's aim was to provide a comparison between observable movement faults on the Hip and Lower Limb Movement screen to 3D Kinematic and kinetic data. In addition a comparison between both HLLMS scores and 3D Kinematic and kinetic data was made for subjects when carrying load vs non-load and also before and after a combat fitness test.

3.1.5 Load Carriage

Consenting RM personnel were assessed pre- and post- an 8-mile load carriage activity (Combat Fitness Test, CFT). The day prior to the 8-mile load carriage (Day-1; pre), volunteers undertook a biomechanical assessment (kinematic and force plate measures) whilst performing four military specific movements (i.e. Single Leg squat, Step down, Deep Lunge, and Landing squat with no-load (i.e. only body weight), and under normal load carriage conditions (25 kg including weapon). On Day-2, volunteers completed the CFT and then repeated the Day-1 measures (post-CFT). Day-1 and Day-2 biomechanical measurements will be completed in loaded and unloaded conditions.

Volunteers were also be assessed using the Hip and Low Limb Movement Screen (H+LLMS). Thus, the four test conditions (i.e. (1) unloaded pre CFT; (2) loaded pre CFT; (3) loaded post CFT; (4) unloaded post CFT), were compared.

Table 3.1 Functional Military Movements

Functional Military Movements Kinematics and kinetics	**Hip and Lower Limb Movement Screen Score**
DAY 1 (Pre CFT)	
Single leg squat	Small Knee Bend (SKB)
Lunge	SKB + Rotation
Step Down	Standing Hip Flexion
Squat	Squat
Landing Squat	Sitting Hip Flexion
Single leg squat + load	Lying Hip ER + Abduction
Lunge + load	Lying Hip IR + Abduction
Step Down + load	SKB + load
Squat + load	SKB + Rotation + load
Landing Squat + load	Standing Hip Flexion + load
	Squat + load
DAY 2 (Post CFT)	
Single leg squat	Small Knee Bend (SKB)
Lunge	SKB + Rotation
Step Down	Standing Hip Flexion
Squat	Squat
Landing Squat	Sitting Hip Flexion
Single leg squat + load	Lying Hip ER + Abduction
Lunge + load	Lying Hip IR + Abduction
Step Down + load	SKB + load
Squat + load	SKB + Rotation + load
Landing Squat + load	Standing Hip Flexion + load
	Squat + load

3.1.6 Participants

Thirty two healthy volunteers were invited to participate in this pilot study from a cross-section of the four main non-logistical companies within 45Cdo. All potential volunteers were deemed fully fit under military medical categorisation and signed fit to participate in the load carriage element of the study by the medical officer. Exclusion criteria included being medically unfit or having had any LL injury in the past 12months were absent.

3.1.7 Sample Size

There are limited published studies in elite infantry populations performing identical movement to determine standard deviations, meaningful effect sizes or clinically relevant changes for the movement measures and the biomechanical measures. The Institute of Naval Medicine has previous data from the Royal Marine Biomechanics Project to inform sample sizes; estimates for the movement measures have been made from (non-military) athletic populations. In terms of measures of movement (Table below), a sample size of 26-32 would be required to achieve a power of 80% and an alpha of 0.05 (single tailed) (Riemann et al 2012, Pollard et al 2010, Macrum et al 2012, Park et al 2013).

Table 3.2 Sample Size Calculation

Description	**SD**	**Clinical Difference**	**Sample Size**
Knee valgus (degrees)	+-3.2	2.5	26
Hip, sagittal plane (ROM)	+- 14.7	10	34
Hip Ext Moment (Nm/Kg)	0.17	0.12	32
Energy absorption at knee Watt/kg	74.1	50	34

3.1.8 Military Functional Movements and load carriage

As described in Chapter 1 the Hip and Lower Movement Score was chosen for its ability to test multiple joint ROM, strength, proprioception and control and as such considered superior to more unidimensional tests of strength or ROM (Kiesel et al 2011). Previous authors have shown value in links between reduced FMS scores and increased injury risk in a military population but as stated in Chapter 1 the FMS lacks common military movements such as the single leg squat, step down or lunge. To date the HLLMS has not been widely tested on military populations and this investigation is the first looking at a Royal Marine Population.

There have also, to date, not been any studies that have looked at more typical military movements and measured these against the HLLMS. This study therefore aims to provide much needed information in this area. Soldiers are typically required to adopt a firing position, move downhill and perform landing squat movement patterns sometimes with significant load carriage. The Military Functional Movements of a lunge, step down, landing squat and single leg squat are used in this study for the collection of the 3D kinematic and kinetic data with the aim of providing a more realistic insight into how Royal Marines may move when under normal conditions. In addition, data has been collected with subjects load-free and carrying a typical weight of 55lbs with rifle in order to provide additional true-to-life information. There have been no other studies to date looking at these aspects combined.

Finally, in order to gather information

3.2 DATA COLLECTION

3.2.1 Military Functional Movements

After the placement of markers, each of the participants was directed to initially complete a serious of functional, multi-joint movements that would commonly be done during military activities. These were first done without load and repeated immediately afterwards with load. The influence that may have been caused by doing 4 movements unloaded first then followed by the same movements loaded was deemed negligible as to affect the results and therefore each subject did the unloaded and then the loaded in the same order. Each movement was allowed three practice movements and each movement was captured 3 times.

Squat - Subjects were instructed to stand shoulder width apart, arms over chest and feet in a comfortable position and perform a squat to thighs parallel with the floor.

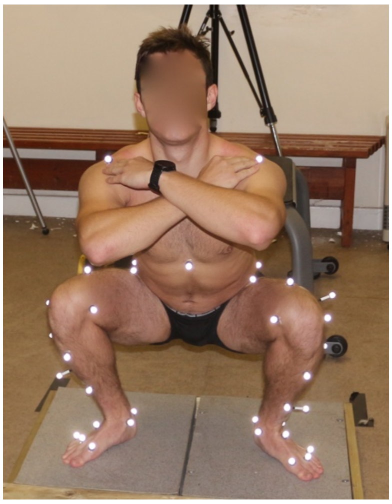


Figure 3-1 Squat

Single Leg Squat - Subjects were to place arms over chest, stand on one leg with the other foot behind with the knee bent and to bend the supporting leg to approximately 45 degrees.

Figure 3-2 Single Leg Squat – With, Without Load

Lunge. Arms folded over chest, lunge forward onto the force plate from a comfortable distance lowering the rear knee to the ground until it gently touches the floor.

Figure 3-3 Lunge with Load

Landing Squat – Arms folded over chest, subjects told to step off the platform (40cm above level of the force plate *) and land in a squat position with each foot on a separate platform, bending the hips and knees as taught in training.

Figure 3-4 Landing Squat

Step Down – Step off platform and land on single leg holding your balance for 1-2 seconds. Ensure rear leg does not remain in contact with the platform at point of landing.

Figure 3-5 Step Down

Kinematic data was determined using a functional approach. First; marker data will be optimised using the Optimal Common Shape Technique (OCST) (Taylor et al 2005) The Star Arc movement will be used to determine the hip joint centre using the Symmetrical Centre of Rotation Estimation (SCoRE) method (Ehrig et al 2006) The knee flexion axis will be determined using the Symmetrical Axis of Rotation Approximation (SARA). (Ehrig et al 2007). Local coordinate systems will then be determined and Euler angle rotation sequences of flexion/extension. The military specific movements will be analysed using the approaches developed under protocol 781/MODREC/2017. The joint centres determined from the kinematic data will form wave forms when expressed relative to time, where these wave forms will be analysed to assess the military specific movements under the different study conditions (Unloaded vs. Loaded; Pre- vs. Post-CFT). Kinetic (GRF) data will be determined from the Force Plate system within the VICON operating system as per normal procedures at Dundee University Department of Motion Analysis. The force plate is calibrated in situ using a calibration rig. This rig allows force at different angles (both vertically and horizontally) to be placed on the force plate. The calibration rig has markers placed along its length, which allows the investigators to confirm that the force line generated by the rig does project along the line of the markers. Thus, both the absolute applied force, and its direction, can be verified as part of the calibration process.

3.2.2 Hip and Lower Limb Movement Screen (HLLMS)

Subjects performed each HLLMS movement as detailed in Chapter 9 and were scored in a standardised manner. The scoring sheet below was used and faults were recorded only as demonstratable or not. Three practice attempts were permitted with verbal prompting to correct faults given by the norater.

Table 3.3 Summary of HLLMS Tests

Hip and Lower Limb Movement Screening Test						
Test	**Verbal Instruction**	**Outcome**				
SKB	Stand on one leg with foot pointing forwards, arms across chest.		Right		Left	
		Does the knee fail to move 2cm past the toes ?	Y=1	N=0	Y=1	N=0
	Place unsupported foot behind with knee at 90˚.	**Does the pelvis tilt forwards?**	Y=1	N=0	Y=1	N=0
	Bend knee in line with 2^{nd} toe until it passes the tape, keeping body upright	**Does the trunk lean forwards ?**	Y=1	N=0	Y=1	N=0
		Is there an increase in knee dynamic valgus?	Y=1	N=0	Y=1	N=0
		Does pelvis fail to stay level on WB side?	Y=1	N=0	Y=1	N=0

SKB + Rotation	SKB as above	**Does the trunk rotate less than 30 degrees?**	Y=1	N=0	Y=1	N=0
	Slowly turn your body 45 degrees to supporting leg then to opposite leg, returning forwards.	**Does the pelvis fail to stay level on the WB side?**	Y=1	N=0	Y=1	N=0
		Does the pelvis follow the trunk rotation	Y=1	N=0	Y=1	N=0
	During rotation keep the pelvis pointing forwards.	**Does the trunk lean forwards?**	Y=1	N=0	Y=1	N=0
Standing Hip Flexion	Stand with feet approx.. hip width and toes forwards or slightly turned out.	**Does the hip fail to flex beyond 90degrees?**	Y=1	N=0	Y=1	N=0
		Does the trunk lean backwards (extend)?	Y=1	N=0	Y=1	N=0

	Arms across chest.	**Does the pelvis begin in or more backwards posteriorly?**	Y=1	N=0	Y=1	N=0
	Keeping supporting knee locked, raise the opposite leg to 110°.	**Does the weight bearing knee bend?**	Y=1	N=0	Y=1	N=0
	Keep back straight.	**Does the pelvis fail to stay level on the weight bearing side?**	Y=1	N=0	Y=1	N=0
Deep Squat	Stand with feet approx.. shoulder width. Arms forwards	**Does the thigh fail to be horizontal with the floor?**	Y=1	N=0	Y=1	N=0
	Keeping body upright, weight even, heels on ground.	**Does the pelvis begin in or more forwards anteriorly**	Y=1	N=0	Y=1	N=0

	Squat until your thighs are horizontal with the floor.	**Does the trunk fail to stay parallel with the shin?**	Y=1	N=0	Y=1	N=0
		Does the bodyweight shift to one side?	Y=1	N=0	Y=1	N=0
Sitting Hip Flexion	Sit with arms across chest	**Does the hip fail to bend just beyond 90 degrees?**	Y=1	N=0	Y=1	N=0
	Keeping back straight and pelvis level	**Does the pelvis begin in or move backwards posteriorly?**	Y=1	N=0	Y=1	N=0
	Raise one leg to 110°.	**Does the trunk lean backwards?**	Y=1	N=0	Y=1	N=0
		Does the pelvis rotate (axial plane) or hitch (frontal plane)	Y=1	N=0	Y=1	N=0
	Keep hip, knee and foot in a straight vertical line.	**Does the foot fail to align with the ankle.knee.hip?**	Y=1	N=0	Y=1	N=0

Side Lying Hip Ab+LR	Lie on one side with bottom leg bent for support	**Does the hip fail to abduct to 45 degrees?**	Y=1	N=0	Y=1	N=0
		Does the pelvis fail to stay vertical (rot up.down)?	Y=1	N=0	Y=1	N=0
Side lying Hip Ab+MR	Laterally (or medially) rotate your leg as far as it will go whilst maintaining pelvis alignment	**Does the leg lose lateral rotation?**	Y=1	N=0	Y=1	N=0
		Does the hip/knee move forwards (flexion)?				
		Does the pelvis fail to stay vertical (rot backwards or forwards)				
	Without losing rotation, raise leg to 45°. Keep Pelvis level.					

3.2.3 Instrumentation and On-site Laboratory set-up

A custom-made temporary gait analysis 'lab' was setup on site at 45 Commando Royal Marine, RM Condor (Figure). Three-dimensional motion analysis was performed using an eight-camera movement analysis system (Vicon 612, Oxford Metrics Ltd, UK). This system incorporates the above-stated infra-red sensitive solid-state cameras for locating and tracking fixed reflective markers through space (Romkes et al 2006).

Figure 3-6 Motion Analysis (On-site) Laboratory

3.2.4 System Set-up

In order to optimise data capture, each of the cameras needed to be placed such that they optimised to capture the maximum amount of motion possible. In this study this included the 3-dimensional space over the force plate in order to capture a variety of movements of individuals of varying heights and dimensions as well as the space above and behind as elevated by a platform at a height of 420mm. A minimum of two cameras are required in order to track images and permit accurate reconstruction of 3D images (Kirtley, 2006a). In this study additional factors such as carrying a large rucksack and rifle could obstruct the view of the cameras and therefore the maximum possible for the space available was utilised.

3.2.5 System Calibration

Accurate capture and recording of 3-Dimensional motion analysis requires accurate calibration of the volume in which the subject being tested performs their movements. There are two aspects to this: The Calibration Frame (Figure 7.7) is placed at a point defined by the meeting point of the x and y axis of a 2-Dimensional plane which is the base of the force plate with the perpendicular axes running along the grooves of the plate. This defines the co-ordinate axes of the 'laboratory space'. During this static calibration any static markers need to be covered over to prevent error. The Dynamic Calibration is then done using the Calibration Wand dynamically. This process involves moving the wand around the laboratory space so that it is detected by as many cameras as possible – a face up orientation is preferred ('the frying pan technique'), in cases where certain cameras are not detecting the wand then the wand was orientated more directly towards this camera. Together these methods allow for the location and orientation of the cameras to be calibrated as well as stated above that the 3-Dimensional co-ordinates of the laboratory space are defined.

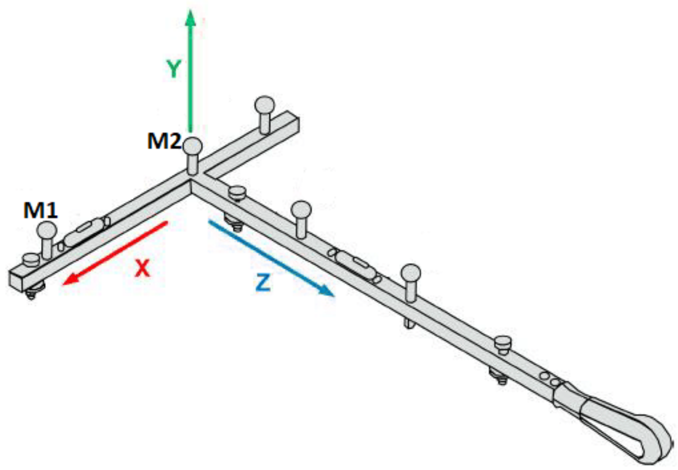


Figure 3-7 7 Calibration L- Frame / Wand

3.2.6 T-Pose

As well as the system and laboratory space calibration. Each subject prior to each trial also had to have their markers placement positions calibrated by the Nexus system. The Nexus system uses a skeleton labelling template (VST) program which as the name suggests defines a generic template based on the chosen marker position model. A subject-specific labelling skeleton (VSK) file needs to be required which holds the information of how that template (VST) fits each individual. This could be understood as the VST file being an off-the-rack suit and the VSK file is the suit following alterations to improve the body-fit.

The way this tailoring is achieved is by performing a T-Pose – the subject having had markers fitted stands with arms outstretched in a T-Pose and a sub-program known in Nexus as a 'pipeline' in ran which calibrates or forms the VSK file for that specific individual for that specific marker placement. Note if data is to be corrected for the same individual on a different day which would the markers to be removed and replaced, the T Pose (Figure 3.8) would have to be re-run due to minor variations in the marker placement each time.

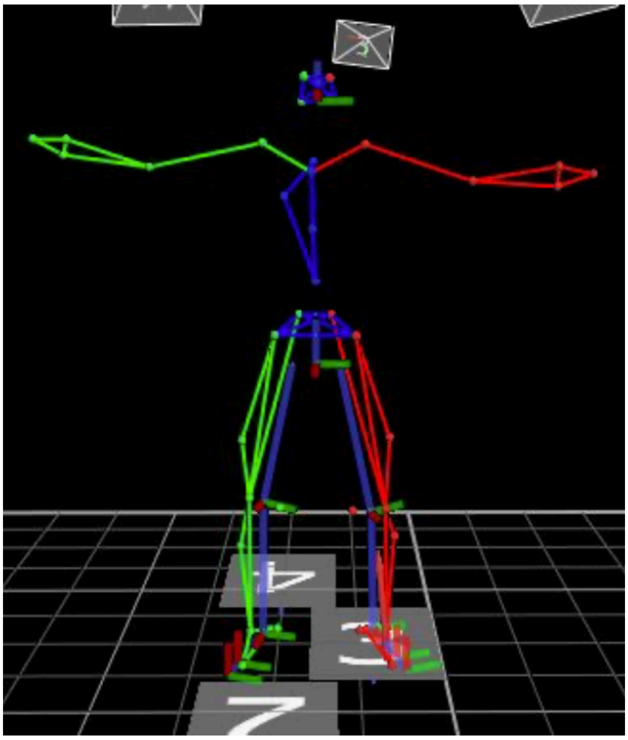


Figure 3-8 T-Pose

3.2.7 Dynamic Pose for SCoRE and SARA

This study trialled the use of a relatively new method of defining knee and hip joint centres using two methods, Symmetrical Centre for Rotational Estimation (SCoRE) and Symmetrical Axis of Rotational Analysis (SARA). For reasons already stated, the author chose to use the PiG system and subsequently only the marker's required for this model were used in the data extraction phase.

3.2.8 The Force Plate System Calibration

Kinetic data from two 0.9x0.4 metre force-plate platforms by AMTI (BP600400) Instruments, Inc, Amherst NY) embedded in a wooden horizontal support platform placed on top of the concrete flooring. The wood acts as a secondary housing structure but the plate itself was positioned directly onto the concrete to minimise any system error that could occur by placement on for example a wooden floor.

The force plates were calibrated by standing a known weight and measuring the displayed force. The vertical and horizontal components to this are then cross-referenced against the previously calibrated poles as defined with the calibration device.

Figure 3-9 AMTI Force Plate.

3.2.9 Subject Preparation and Marker placement

Subject set up / Marker Placement Participants were asked to undress down to shorts or underwear and were asked to stand in a relaxed position whilst fifty-four VICON markers were taped into position by investigators. Previous reliability testing had been completed to show accurate marker placement. The markers were as follows:

- 2cm Medial to lateral iliac crest
- 2cm lateral to lateral iliac crest
- Anterior Superior Iliac Spine
- Posterior Superior Iliac Spine
- Superior thigh marker - midpoint ASIS to patella on anterior/lateral and posterior thigh
- Inferior thigh marker – mid-point between superior thigh marker and patella on anterior/lateral/posterior thigh
- Lateral epicondyle of the femur
- Medial epicondyle of the femur
- Superior tibia marker – level with tibial tuberosity or anterior/lateral/posterior shank
- Inferior tibia marker mid-point between superior tibia marker and ankle on anterior/lateral/posterior tibia
- Anterior midshaft of the tibia
- Posterior lower leg
- Superior calcaneus
- Inferior calcaneus
- Lateral malleolus of the ankle
- Proximal third metatarsal
- Third metatarso-phalangeal joint
- Fifth metatarso-phalangeal joint
- Dorsal aspect of 1st metatarsal head.
- Acromion process

- C7 Spinous Process
- Sternum
- Centreline Sterno-clavicular joint.

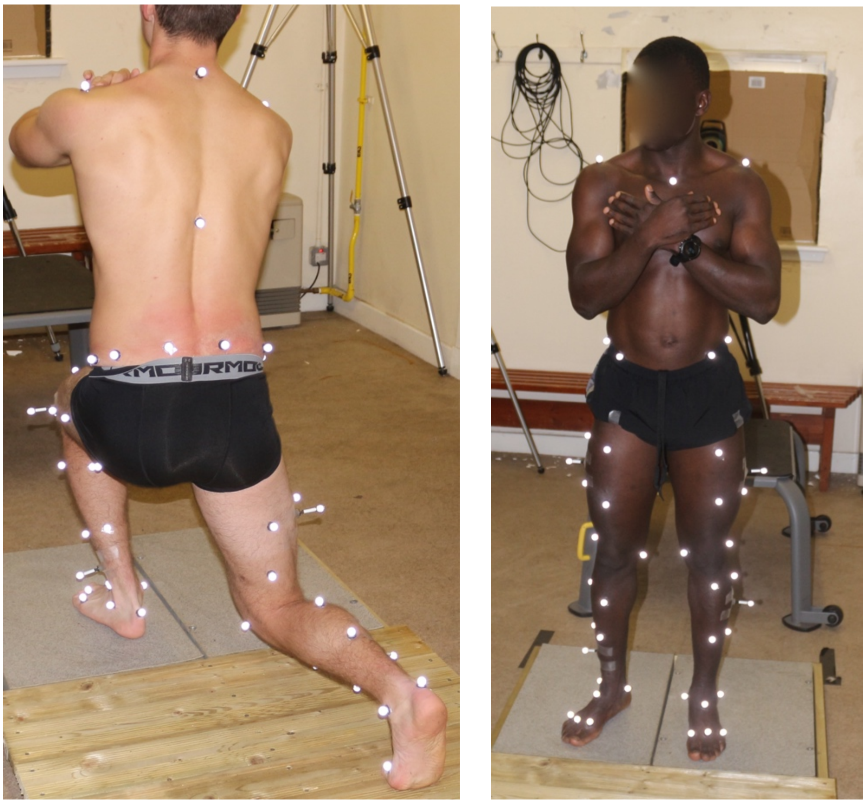


Figure 3-10 Marker In-Situ

3.2.10 Repeatability of the IMAR Measurement

Consistency and repeatability of measurement is referred to as reliability and concerns the ability to collect quantitative data with minimal errors. Factors such as the temperature of a building or vibration of certain types of buildings could for example be a factor but the ability to consistently capture data depends primarily on the 'laboratory' and subject setups described above.

It is important to remember that small deviations in data will always exist but it remains important to identify and quantify each of these as far as is possible. In this way any conclusions drawn from results will be able to take into account inherent data collection errors.

A study by Webster et al (2005) found good reliability of the Vicon system for capturing kinetic and kinematic data using a set-up very similar to the one in this study and one that has been validated by the Institute of Motion Analysis for use over several studies (Rao et al 2005).Several studies have demonstrated the repeatability of lower limb kinematic and kinetic data using the Vison system (Yavuzer et al 2008, McGinley 2009).

As described above, Force Plate readings were calibrated using a simplified version of the method described by Cadraro et al (2009) and the equipment was placed directly onto the concrete floor and levelled appropriately with a digital spirit level. The Force Plate system has undergone reliability testing by both its' manufacturers and independent research (Fortin et al 2008).

Marker Placement Repeatability - The author of this work is an experienced clinician with considerable knowledge and experience locating the anatomical landmarks used in marker placement. In addition a reliability protocol used at the IMAR was followed whereby marker placement was performed six weeks apart and tested for acceptable levels of error.

CHAPTER 4

4.1 THE HIP AND LOW LIMB MOVEMENT SCREEN

The Hip and Low Limb Movement Screen (HLLMS) developed by Botha et al (2013) is a new tool, specifically designed to focus on assessing multiple-joint alignment with a view to screening for movement faults that could lead to increased risk of injury or osteoarthritis (OA) (Wilson et al 2018).

It consists of seven tests, small knee bend(SKB)(figure 4.1), SKB with trunk rotation (SKB+Rot)(figure4.2), standing hip flexion (Figure 4.3), deep squat (Figure 4.4), sitting hip flexion (Figure 4.5), hip abductor rotation stabiliser test with medial and lateral rotation (Figure 4.6). The participants were given three to six practice attempts and given guidance if required to correct movements. The tests are designed to test an unfamiliar movement but it is rather testing the ability to do the movement correctly as opposed to the cognitive ability of understanding what the task is. The tests were performed in the same order each time and the same order as detailed here.

4.2 HIP AND LOWER-LIMB MOVEMENT SCREEN (HLLMS) – DETAILED DESCRIPTION

The HLLMS was scored by a single investigator who had completed training at Southampton University in the administration of the tool. The investigator also completed a reliability study on 20 video subjects comparing scores from experienced staff at SOTON with an average of 90% reliability. Video footage was also be taken for further analysis directly in front of the subject and at 90 degrees. Each of the above movements were performed with and without load with the exception of the Sitting Hip Flexion Test and the Side Lying Hip Tests which were impractical to perform carrying Bergen and rifle.

4.2.1 Knee Bend

This test is a commonly used movement to assess an individuals' postural balance, control and lower body alignment (Crossley et al 2011).

In both the Small Knee Bend and Small Knee Bend with Trunk Rotation Tests, the participant stands on one leg, which is placed in a position with the 2nd metatarsal aligned along the 10° neutral line of weight transfer to ensure a correct foot position. The pelvis is maintained level and the trunk positioned vertical. The participant was instructed to perform a small knee bend (SKB), by flexing the knee and dorsi-flexing the ankle while keeping the heel on the floor. To standardise the position a piece of tape will be placed on the floor in a T-shape. The participant was instructed to stand with the long axis of the foot aligned to the stem of the T; the second toe placed on the stem. The participant was asked to bend the knee until he no longer could see the line along the toes (corresponding to 2-8cm over the 2nd metatarsal)(1). The researcher then marked this distance with a panel. The pelvis is maintained level and the trunk positioned vertical. The participant is instructed to perform a small knee bend (SKB), by flexing the knee and dorsi-flexing the ankle while keeping the heel on the floor touching the knee against the panel, and then returning to extension.

Verbal instructions

- Stand on one leg with your foot pointing forward.
- Place the unsupported foot behind you by bending your knee.
- While keeping upright, keeping your pelvis and heel in position, bend your knee so that your knee keeps inline and moves over your 2nd toe.
- Do you understand the instructions?

Figure 4-1 Small Knee Bend

4.2.2 Small Knee Bend with Rotation Test

The above test was included for reasons similar to the SB with the additional component of having to control the pelvis whilst rotating the trunk. Initially deemed important for footballers this could have importance with Royal marines – who may have to maintain a line of direction of travel whilst rotating the trunk into an oblique firing position. This ability to disassociate one movement form another is common on low back pain studies in athletes (Comerford and Mottram, 2012)

During this test the participant is asked to rotate the shoulders and upper trunk around from side-to-side while keeping the pelvis from moving, maintaining a forwards-facing position.

Verbal instructions

- Stand on one leg with your foot pointing forward.
- Arms placed across your chest.
- Place the unsupported foot behind you by bending your knee.
- While maintaining an upright torso, keeping your pelvis and heel in position, bend your knee so that your knee aligns along your 2nd toe.
- While holding this position turn your upper body to the left and right looking over your shoulder
- Do you understand the instructions?

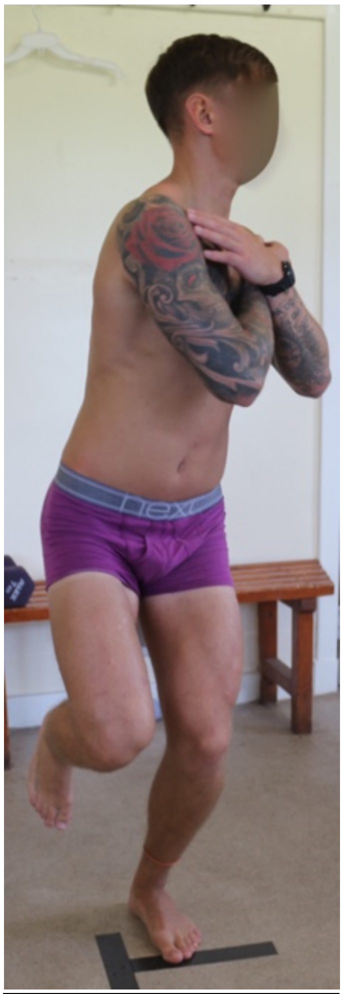


Figure 4-2 Small Knee bend with Rotation

4.2.3 Standing Hip Flexion Test

The participant stands with the pelvis maintained level and the trunk vertical. The participant is instructed to lift the leg so that the hip flexes to 110° with knee flexion.

This test tests the combination of hip flexor and hip abductor control – the ability to lift the thigh whilst maintaining control at the pelvis.

Verbal instructions

- Stand with your feet approximately pelvis width apart and the toes pointing forward.
- Place your arms across your chest.
- While maintaining an upright torso, keeping your pelvis steady and knee locked on the standing leg, raise the opposite leg, flexing your hip to 110°.
- Do you understand the instructions?

Figure 4-3 Standing Hip Flexion

4.2.4 Deep Squat

The participant stands in a position with the 2nd metatarsal aligned along the 10° neutral line of weight transfer to ensure a correct foot position. The participant is instructed to perform a squat, by flexing the knees and dorsi-flexing the ankle while keeping the heels on the floor. During this test the body weight must be kept on the heels rather than the ball of the foot. The line of the femur should be horizontal and align on the 10° neutral line of weight transfer whiles the knees align to the 2nd metatarsal. The trunk must be maintained parallel with the tibia or vertical.

This tests the ability to maintain alignment at the hips, knees and ankles whilst maintaining lumbar and thoracic postural control.

Verbal instructions

- Stand with your feet approximately shoulder width apart and the toes pointing forward.
- Place your arms forward.
- While maintaining an upright torso, keeping your heels in position and your weight equal, move down as deep as possible aligning your knee to your 2nd toe.
- Do you understand the instructions?

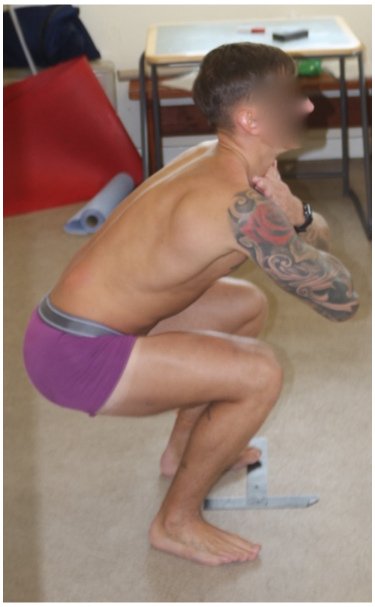


Figure 4-4 Squat

4.2.5 Sitting Hip Flexion Test

This test the ability to maintain hip alignment (rotation) and pelvis posture whilst actively recruiting the hip flexor muscles.

The participant sits in a position with hip and knee angles flexed to 90°. The pelvis is maintained level and the trunk positioned vertical while the feet is not touching the floor. The participant is instructed to flex the hip to 110°.

Verbal instructions

- Sit with your arms across your chest.
- While maintaining an upright torso, keeping your pelvis steady raise the opposite leg, flexing your hip to 110°, making sure to maintain your foot aligns with the ankle, knee and hip.
- Do you understand the instructions?

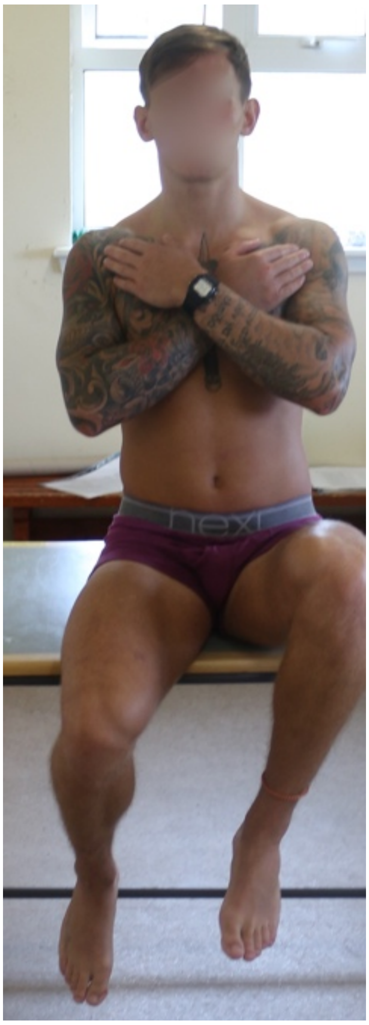


Figure 4-5 Sitting Hip Flexion

4.2.6 Hip Abductor Lateral Rotation Test

The uppermost leg, the hip is laterally rotated as illustrated. Lie on your side with your bottom leg bent for support. While maintaining the leg straight, with the upper body straight and your leg turned outward, lift your leg towards the ceiling 45° while keeping your pelvis steady.

This tests The hip abductor rotation stabiliser tests assess trunk and pelvic control during active lower limb movement from an unstable position (Nelson-Wong et al., 2009)

Verbal Instructions

- Lie on your side with your bottom leg flexed for support.
- While maintaining leg extension, a straight back and your leg turned outward, lift your leg towards the ceiling (approximately 45° while keeping your pelvis steady.
- Do you understand the instructions?

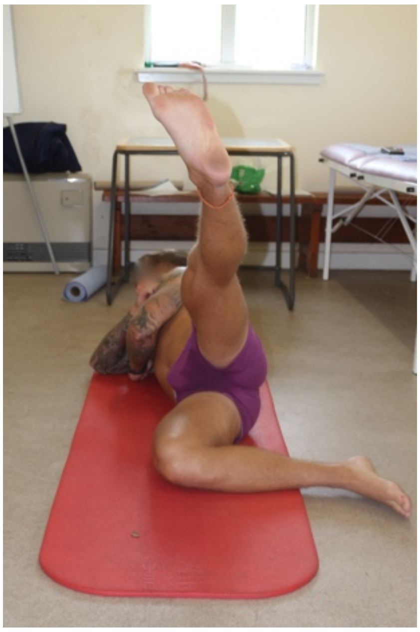


Figure 4-6 Hip Abduction Lateral Rotation

4.2.7 Hip Abductor Medial Rotation Test

As for Lateral Rotation test but with the uppermost leg rotated into lateral rotation 45 degrees.

Verbal Instructions

- Lie on your side with your bottom leg flexed for support.
- While maintaining leg extension, a straight back and your leg turned downward, lift your leg towards the ceiling (approximately 30°) while keeping your pelvis steady.
- Do you understand the instructions?

4.3 RELIABILITY OF THE HLLMS

4.3.1 Inter-Rater Reliability of scoring the Hip and Low limb Movement Score

Since data collection, unpublished research at Southampton University has highlighted some potential strong and weak aspects of inter-rater reliability of the HLLMS (Wilson et al 2018).

Of importance is to consider not just whether the overall score and this screen has good inter-rater reliability but also that it has so for individual components.

The overall mean inter-rater agreement ranged from 0.6-0.8 demonstrating good to excellent reliability for overall scores.

Looking at individual criterion however showed a much larger range with AC1 values from -0.47 to 1.00. Largely however individual components with the exception of "Does the pelvis begin in or move forwards?" and 'Does the pelvis tilt forwards?' were deemed acceptable. These potential shortcomings are discussed later.

Wilson et al (2018) recommended among other things, suitable training for assessors of the HLLMS in order to improve inter-rater reliability. The author in the current study spent two full days as a guest at Southampton University learning about and training in the scoring of the Hip and Low Limb Movement Score. Under instruction by an experienced Physiotherapist and PhD student Nadine Boysoon, the author practiced performing and scoring the movements required of subjects for this study.

Thereafter the author practiced repeatedly scoring the system on available patient and finally took an inter-rater reliability test designed by Southampton University. This involved the scoring or 20 pre-recorded subjects and performing and entering the results onto a spreadsheet which calculated reliability coefficients – see Results section.

Since data collection for the current paper, Southampton University have completed a detailed reliability and validity assessment and recommendations of changes suggested to the HLLMS and how these relate to the current research findings will be addressed in the discussion section of this paper (Wilson et al 2018).

4.3.2 Reliability of the HLLMS due to Subject Performance Variability

Wilson et al (2018) also looked at several different aspects of the reliability of the performance of the HLLMS. In other words, the same individuals at different times performed the same movements motional analysis equipment was used to determine the kinematic consistency of these movement. There was much variability. The SKB for example ranged from poor to excellent (0.27-0.97) – this aspect will in this papers' final discussion.

CHAPTER 5

5.1 RESULTS OF HLLMS SKB, KNEE VALGUS FAULT, PELVIS DROP FAULT COMPARED WITH KNEE, HIP, PELVIS KINEMATICS AND KINETICS

Statistics were first calculated on knee, hip and pelvis kinematics and kinetics of peak and ROM values for the Single Leg Squat, Loaded Single Leg Squat, Step Down, Lunge and Loaded Lunge for the left leg compared against the Hip and Lower Limb Movement Screen (HLLMS), Small Knee Bend (SKB), knee valgus and hip drop faults.

Across all the comparisons, with a 95% confidence level, no significant results were found. However, a trend emerged involving in particular the knee and hip kinematics in which the Y and Z kinematics approached statistical significance for several of the functional movements.

Table 5.4 shows the descriptive statistics of those notable increases in the Means with additional Statistical Results in Tables 5.5-5.7 of the aspects approaching statistical significance.

Tables 5.1-5.3 below illustrate, in particular the increases in Knee Y (Purple) and Z (Light Green) Angle ROM and max excursions.

Table 5.1 Left Loaded Single Leg Squat, Excursion ROM, HLLMS Knee Fault Y/N Groups

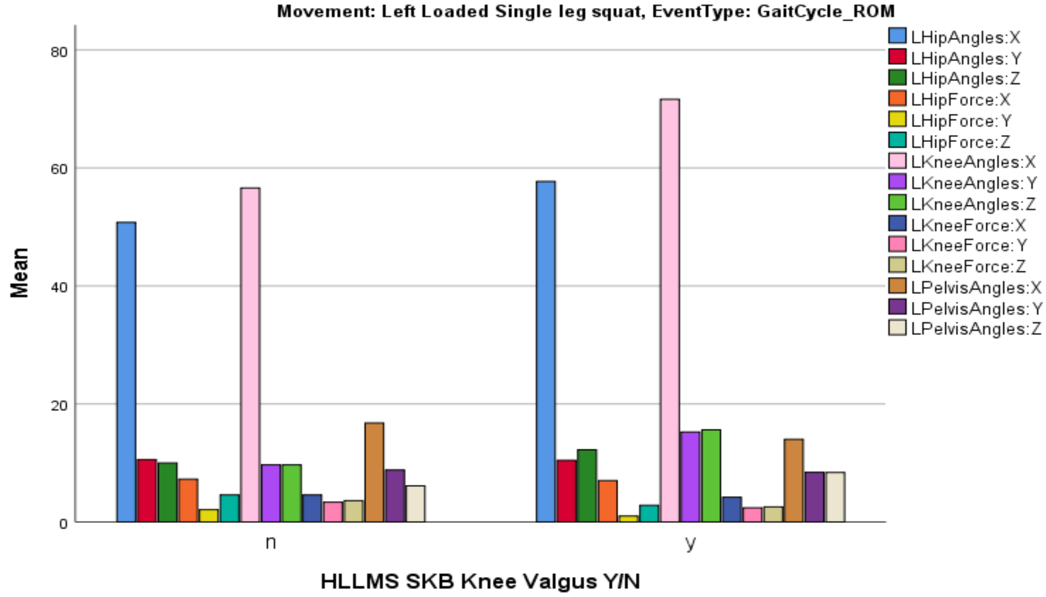


Table 5.2 Left Loaded Single Leg Squat, Excursion ROM, HLLMS Knee Fault Y/N Groups

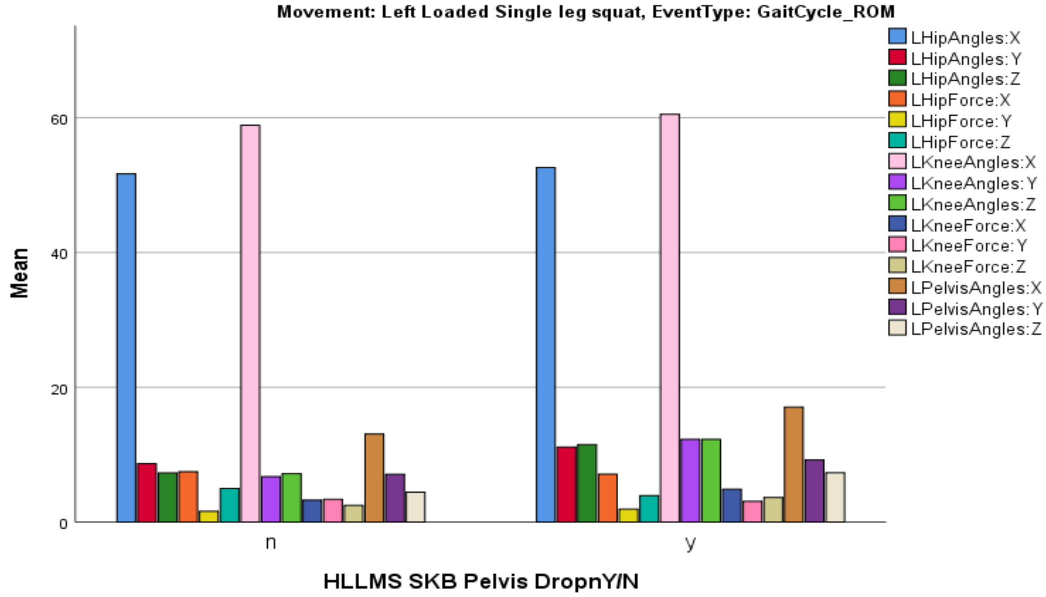


Table 5.3 Left Single Leg Squat, Peak Excursion Values.

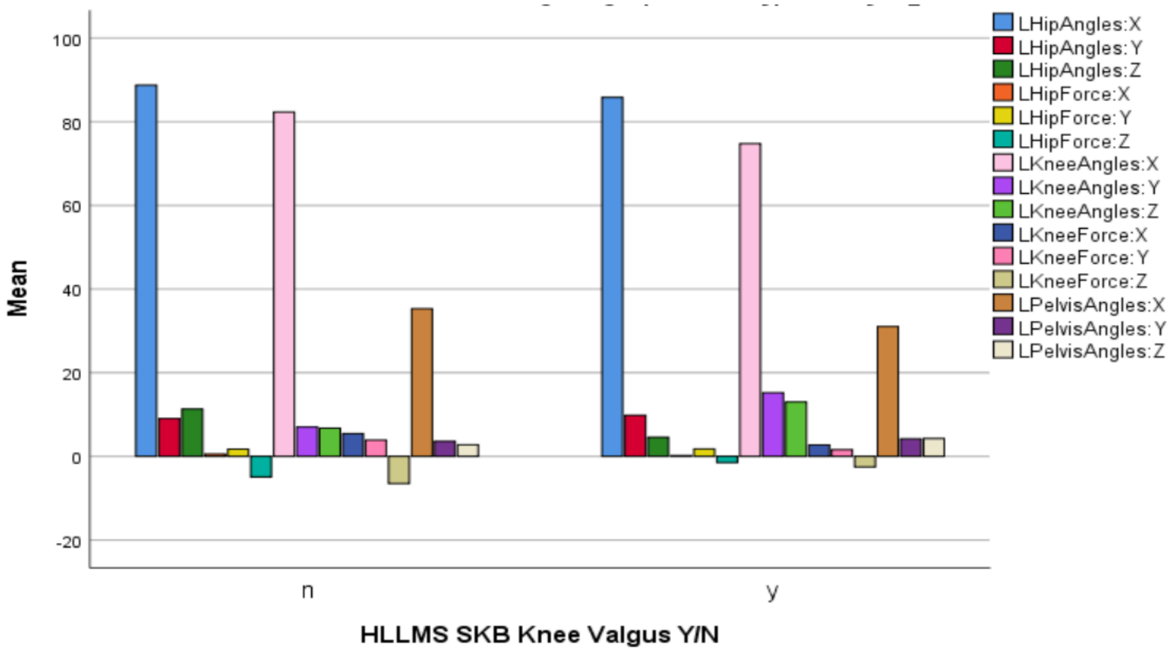


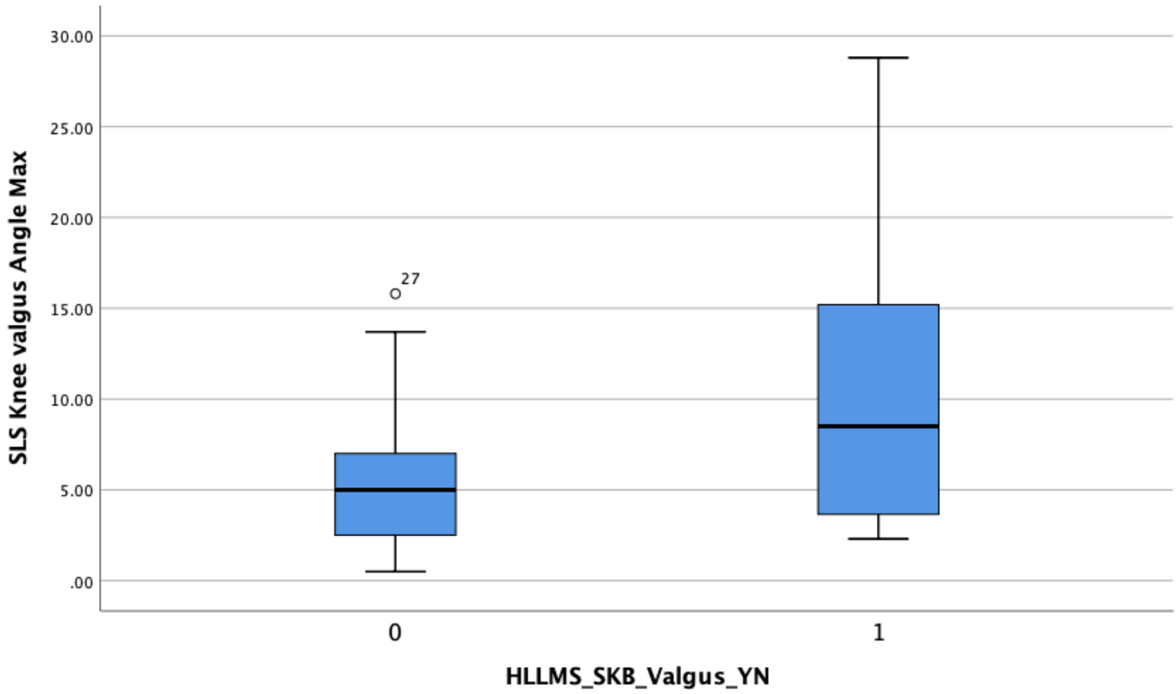
Table 5.4 Left Single Leg Squat, Max Excursion Values, HLLMS Knee Fault Y/N Groups

Movement	**Kinematic / Kinetic Measured**	**HLLMS Movement Error**	**N**	**Mean Value : No**	**Mean value : Yes**	**t-test p-value**
Single Leg Squat	Knee Y Angle – Valgus Max excursion value	Knee valgus Yes / No	22	5.81	11.04	0.09

Loaded Single Leg Squat	Knee Y Angle – Valgus Max excursion value	Knee valgus Yes / No	14	0.53	5.28	0.34
Loaded Single Leg Squat	Knee Rotation ROM	Knee valgus Yes / No	7	5.31	12.45	0.83
Loaded Single Leg Squat	Knee Y Angle ROM	Knee valgus Yes / No	7	4.28	5.10	0.26
Loaded Single Leg Squat	Knee Y Angle ROM	Pelvis Drop Yes / No	19	6.73	12.78	0.09
Loaded Single Leg Squat	Knee Z Angle ROM	Pelvis Drop Yes / No	19	7.17	12.05	0.16
Loaded Single Leg Squat	Hip Y Adduction Angle ROM	Pelvis Drop Yes / No	17	1.59	1.90	0.84

Loaded Lunge	Hip IR Angle, Max excursion value	Pelvis Drop Yes / No	8	1.55	8.66	0.07

Table 5.5 Single Leg Squat, Knee Max Valgus Excursion. HLLMS Knee Valgus Y/N Groups



5.1.1 Outliers

The above box plot (Graph 9.4) shows an outlier in the No Fault Group in the Single Leg Squat, HLLMS Knee Valgus Y/N t-test. The author decided as this was not an extreme outlier that the value was left unchanged. Methods to modify outliers include removing the value, replacing it with the closest non outlying value or using a different statistical analysis. As this outlier was in the No group it's presence would increase the risk of a Type2 not a Type 1 error and the author decided that this was the preferred solution.

5.1.2 Equal Variance

For equal variances to be assumed, the Leven's Test requires a Sig value greater than 0.05. The t test produces values for variances assumed and not assumed. The appropriate value is chosen depending on the Leven's test for equal variance.

Table 5.6 Single Leg Squat, Knee Valgus Max Excursion, t test HLMS Knee Valgus Y/N

Leven's Test		**t- test**				
F	Sig	t	df	Sig (2 tailed)	Mean Difference	Std Error Difference
5.398	0.31	-1.74	20	0.095	-5.23	2.98

Table 5.7 Loaded Single Leg Squat, Knee Y ROM, t test HLLMS Pelvis Drop Y / N

Leven's Test		**t- test**				
F	Sig	t	df	Sig (2 tailed)	Mean Difference	Std Error Difference
	P<0.05 Equal Variance not assumed			0.09	5.88	3.24

Table 5.8 Loaded Lunge, Hip Z Max Excursion - Pelvis Drop (HLLMS)

Leven's Test		**t- test**				
F	Sig	t	df	Sig (2 tailed)	Mean Difference	Std Error Difference
1.410	0.288	2.295	5	0.070	7.11	3.10

5.2 RESULTS OF CORRELATION TESTS FOR HLLMS SUB SCORES AND HLLMS TOTAL SCORES AGAINST KNEE, HIP AND PELVIS KINEMATICS AND KINETICS

Correlation coefficient's Spearman's , Kendall were done for Hip,Knee, Pelvis angles on X,Y,Z planes and Hip and knee forces on X,Y,Z planes for each of the functional movements and each of these were correlated against the following different scores of the HLLMS.

1. SKB Total
2. SKB + Load Total
3. SKB + Rot Total
4. Stand Hip Flexion Total
5. Squat Total
6. Hip Ab + LR Total
7. Hip Ab + MR Total
8. HLLMS Total Score

Results with a correlation of less than 70% or without statistical significance were discarded and the resulting data is recorded on table 5.9.

Table 5.9 Correlation findings of kinematic/ kinetics to HLLMS scores.

Movement	**Kinetic / Kinematic**	**HLLMS**	**Correlation Coefficient**	**p-value**	**N**
Loaded Step Down	Hip IR angle	SKB Total	0.734	0.060	7
Loaded Lunge	Hip adduction angle	SKB Total	0.865	0.0060	8
Lunge	Knee ER angle	SKB Total	0.728	0.017	10
Loaded Lunge	Knee ER angle	SKB Total	0.865	0.06	8

5.3 RESULTS OF NON-PARAMETRIC STATISTICAL TESTS WERE COMPLETED COMBINING KINEMATIC VALUES FOR KNEE AND HIP IN Y AND Z PLANES AGAINST HLLMS SUB SCORES AND TOTAL SCORE. THE FOLLOWING STATISTICAL

1 – Knee Hip YZ Largest deviation vs SKB Total

2 – Knee Hip YZ Largest deviation vs HLLMS Total

3 – KneeHip YZ Largest deviation vs SKB Hip drop Knee valgus combined

4 – Knee valgus Hip Add Pelvis Drop angles combined vs SKB total

5 – Hip Knee Y largest HLLMS Total

There were no significant correlations found on completion of these tests.

5.4 RESULTS FOR HLLMS SCORES PRE/POST COMBAT FITNESS TEST (CFT) ; WITH AND WITHOUT LOAD

McNemar statistical tests to compare non-continuous ordinal data from the HLLMS were used to compare HLLMS Scores before and after an 8mile load carriage as well as values with and without load. The results of these are summarised in Table 5.10 with details of statistical tests in Tables

Table 5.10 HLLMS Total Scores, Pre / Post CFT

HLLMS Measure	**Pre-Post Variable**	**Statistical test used**	**Significant difference seen?**
SKB Knee valgus Y/N	With vs without weight	McNemar	No
SKB Hip drop Y/N	With vs without weight		
SKB Total	With vs without weight		
HLLMS Total	Pre Post CFT	Wilcoxon Signed Rank Test	Yes

Wilcoxon signed Rank tests was used to compare HLLMS Pre and Post CFT scores showing a significant difference p=0.08 between the groups.

Table 5.11 Descriptive Statistics for HLLMS Pre / Post CFT

Total N	30
Test Statistic	319.500
Standard Error	43.826
Standardized Test Statistic	2.658
Asymptotic Sig.(2-sided test)	.008

Table 5.12 Wilcoxon Signed Rank Test for HLLMS Pre / Post CFT

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between HLLMSTotal_All_PreCFT and HLLMSTotal_ALL_PostCFT equals 0.	Related-Samples Wilcoxon Signed Rank Test	.008	Reject the null hypothesis.

Table 5.13 Descriptive Statistics for HLLMS Pre / Post CFT

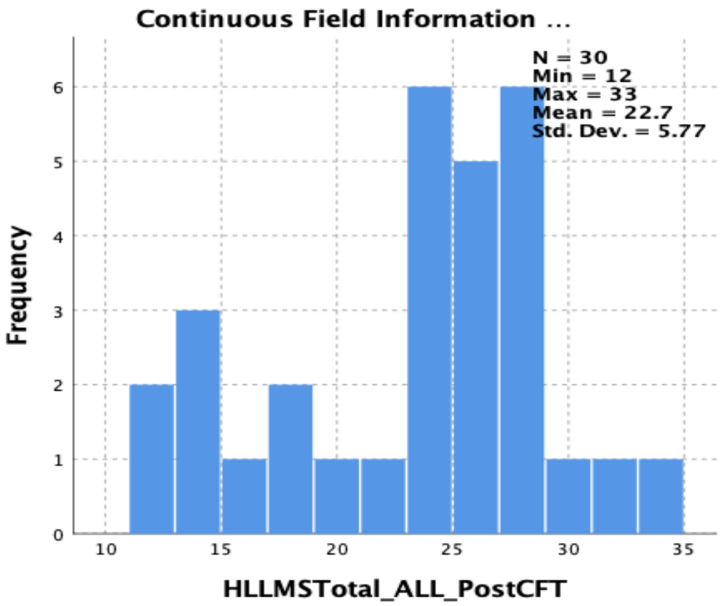


Table 5.14 Descriptive Statistics for HLLMS Pre / Post CFT

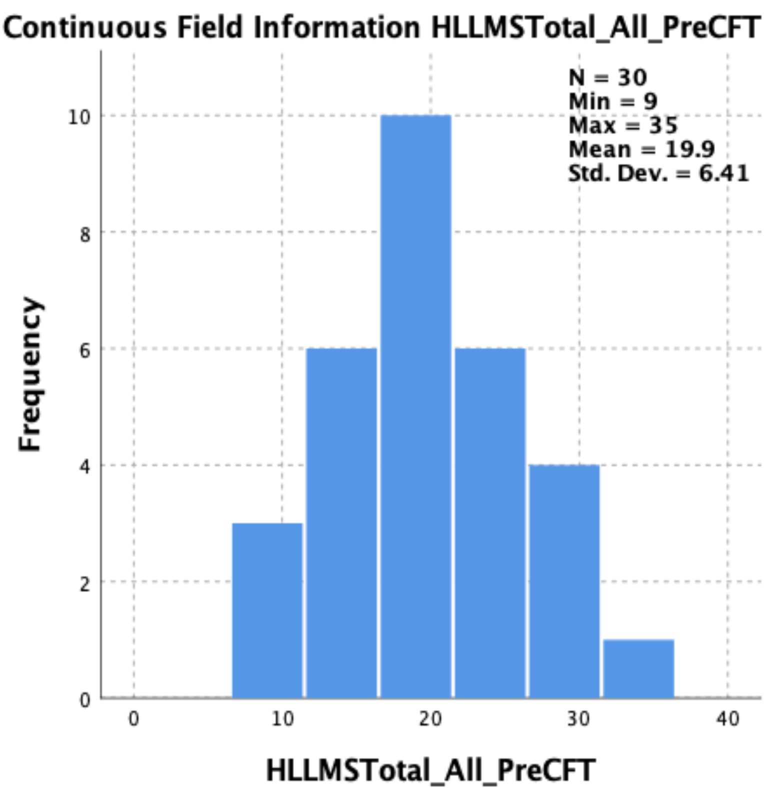
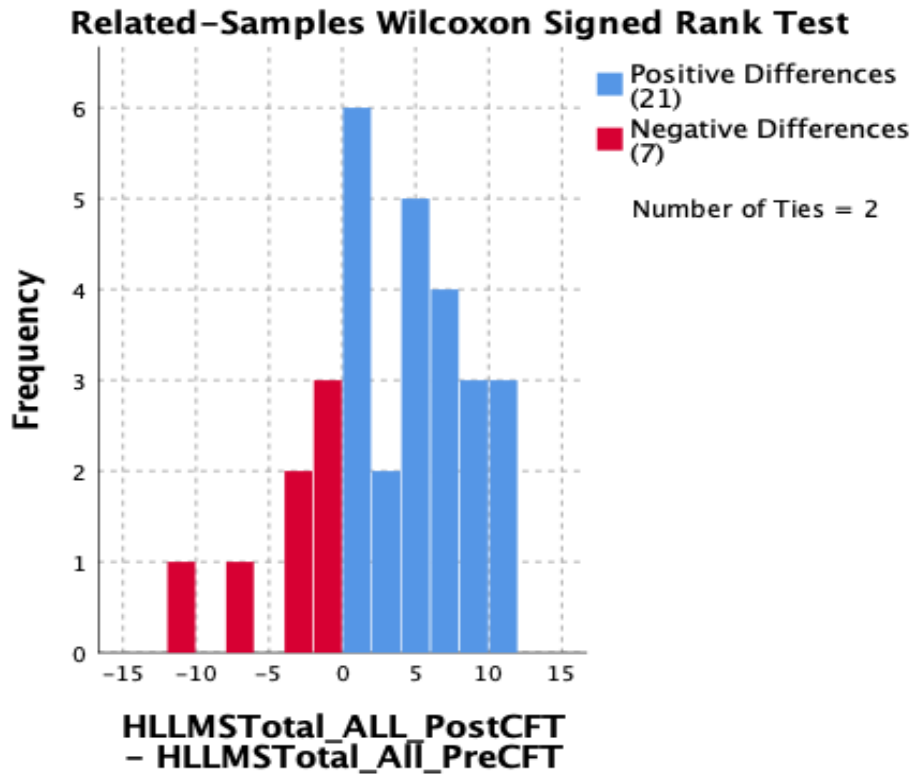


Table 5.15 Descriptive Statistics



5.5 MANN-WHITNEY U TEST COMPARING HLLMS TOTAL SCORE FOR GROUPS HLLMS KNEE VALGUS FAULT Y / N

The Mann Whitney U test was used to compare the HLLMS Total scores with the individual HLLMS Knee Valgus Fault in the SKB Test. There was a Mean difference found of greater than 11 points in the HLLMS Knee Fault Yes vs No group, P<0.001. Descriptive and statistical results detailed below in Table5.14 and Table 5.15.

Table 5.16 HLLMS Total Scores for Knee Valgus Y / N Groups

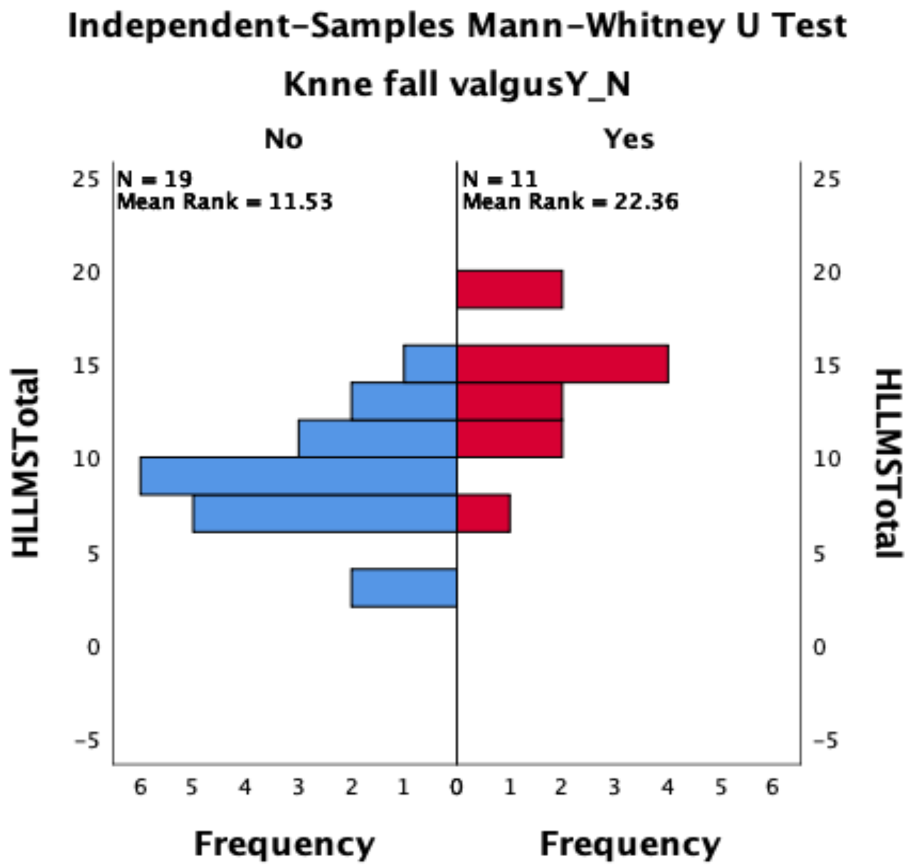


Table 5.17 HLLMS Total Scores for Knee Valgus Y / N Groups

Independent-Samples Mann-Whitney U Test Summary

Total N	30
Mann-Whitney U	180.000
Wilcoxon W	246.000
Test Statistic	180.000
Standard Error	23.107
Standardized Test Statistic	3.267
Asymptotic Sig.(2-sided test)	.001
Exact Sig.(2-sided test)	.001

5.6 VICON NEXUS KINEMATIC DATA WITH/ WITHOUT LOAD COMPARISON

Paired T Test was carried out comparing kinematic and kinetic values with and without load looking at the Y and Z planes of the hip and knee. There was a significant difference p<0.001 for rotational forces at the knee in the loaded vs unloaded group, descriptive and statistical tests detailed below in Tables 5.16 – 5.17.

Table 5.18 Descriptive Results for Knee Z Kinetics With / Without Load

Descriptives

			Statistic	Std. Error
difference	Mean		2.7961	.49437
	95% Confidence Interval for Mean	Lower Bound	1.7531	
		Upper Bound	3.8392	
	5% Trimmed Mean		2.4423	
	Median		2.6050	
	Variance		4.399	
	Std. Deviation		2.09746	
	Minimum		1.19	
	Maximum		10.77	
	Range		9.58	
	Interquartile Range		1.35	
	Skewness		3.542	.536
	Kurtosis		13.973	1.038

Table 5.19 Results for Knee Z Kinetics With / Without Load

Paired Samples Statistics

		Mean	N	Std. Deviation
Pair 1	KneeZForcceMaxIR_Unloaded	9.4539	18	2.63706
	KneeZForceMaxIR_Loaded	12.2500	18	1.39825

Table 5.20 T Test Results for Knee Z Kinetics With / Without Load

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	KneeZForcceMaxIR_Unloaded & KneeZForceMaxIR_Loaded	18	.612	.007

CHAPTER 6

6.1 DISCUSSION OF RESULTS

The primary aim of this study was to test the predictive criterion validity of the Hip and Lower Limb Movement Screen (HLLMS). In other words, its ability to predict movement faults seen on visual testing which are then replicated in other situations.

In order to fully test the Research Hypothesis the HLLMS was examined at a macro (total scores) and micro (individual component parts) level as several authors have recommended both aspects require equal scrutiny (Ageberger et al 2010, Horan et al 2014). Any movement screen used to identify movement dysfunction or fault will likely detect a fault present in more than a single movement especially where similar movement patterns are repeated. Therefore any screen used in such a manner should show a level of correspondence between itself and typical movements employed by whichever cohort is using the screen. If it does not, there may be a justification to question the relevance of such a tool in these and similar circumstances.

The author's experience from clinical practice was that a movement fault seen at the pelvis, hip or knee, on viewing a single leg squat, would also be present in many real-life movements. The literature suggests that movement faults seen at these joints are crucial in helping us interpret and avoid problems such as ACL trauma or PFPS (Hewett 2006, 2009 Griffin 2005, Krosshaug 2007). The component parts of the HLLMS therefore which scored Knee Dynamic Valgus Fault and Pelvis Fail to Stay Level were considered fundamental to evaluating the primary hypothesis of this study and for this reason formed our primary analysis. Thereafter the analysis was broadened to consider combined scores and finally, the total score of the HLLMS.

Of the initial analysis of the 2 individual movement faults, this paper found significant trends for Medial Knee Displacement on the Single Leg Squat (Functional Movement) between HLLMS Valgus fault and No-Fault groups (p=0.09), and for Pelvis Drop (Did the Pelvis Fail to Stay Level?) group for Loaded Single Leg Squat for Knee Y plane Displacement ROM (p=0.09) and for Hip Z plane, rotational displacement ROM (p=0.07).

These values taken individually represent a significant trend - when taken in combination they suggest a consistent trend of knee valgus, hip valgus and IR peak excursions seen during the Military Functional Movements with faults observed at the knee and hip during the HLLMS.

Interestingly, Wilson et al (2018) who compared HLLMS scores against kinematic findings taken during the HLLMS testing found mixed results and concluded the HLLMS Knee Valgus criteria showed poor validity. The results of this study go some way towards strengthening the utility of aspects of the HLLMS but also like Wilson et al (2018) demonstrate inconsistencies in results and the potential complexities around attempting to measure a 2 Dimensional observed movement pattern with single joint 3D kinematics. The other significant difference between this thesis and the work by Wilson et al (2018) being that the kinematics in the present study were taken not concurrent to the HLLMS data collection but at a different time and with different and arguably more relevant movement patterns. That this study was still able to demonstrate repeated trends and correlations between the HLLMS and the military movements suggests a strong argument for the use of this tool with a Royal Marine population as well as other similar groups.

Considering further the links between the hip and the knee - In the present study, the Pelvis Drop Fault Group, demonstrated an increase in the Knee Max Valgus ROM (p=0.09) and the Knee Internal Rotation ROM(p=0.16). Again, taken individually these show a trend and taken as a group the pattern of differences are consistent with suggestion by Ageberger et al (2010) that 3 dimensional differences at both the knee and hip could explain single movement faults seen in a single plane. It may therefore be important to avoid thinking about movement faults in a single plane such as knee valgus or hip adduction but as combinations of several planes and several joints.

Clinically, the knee remains an important mid link in the LL kinetic chain, it is certainly where many injuries occur, and poor hip control has been widely discussed as a factor in knee injury (Frohm et al 2012). Considering a movement fault at either the hip or the pelvis on the Y plane, this movement fault must affect the alignment of the knee. In fact a movement fault at the knee is a result of a problem proximally or distally, not isolated to the knee itself. In other words, when the knee is recorded clinically as a valgus movement fault the movement fault will often be related to a pelvis drop or a hip adduction, or a combination – Figure 6.1

Once the rotational component of these movements are also considered it becomes more apparent how difficult it can be to use a single-plane, single-joint movement fault when the reality is multiplanar combinations at the hip and knee.

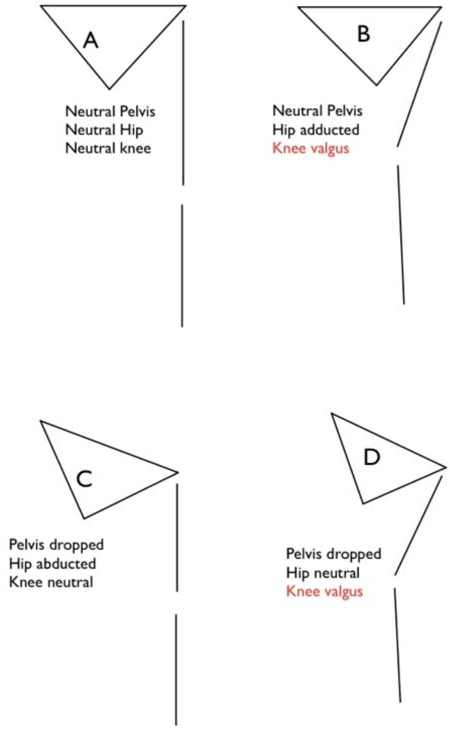


Figure 6-1 Schematic of pelvis, hip relation to knee valgus on single plane.

Myer at al (2011) proposed an interesting algorithm which combined knee valgus deviation angles with certain anthropometric data in an attempt to identify individuals at risk of ACL injury. There are however, to date, no known research studies looking at an algorithm which combines hip, knee and pelvis kinematic data in a compound value that may be used to measure movement faults such as those scored in the HLLMS. The author considered the above 3 Dimensional problem and in an attempt to find a more valid method of assessing the value of the HLLMS, the author trialled a multitude of combinations of kinematic values of joints and planes in an attempt to find a solution to this problem and in order to consider the possibility of a new model of assessment The results of this analysis did not produce any significant results but in doing so the depth of the problem was considered.

Future validity studies of movement screens such as the HLLMS may indeed need consider how the tool itself is measured and a 3-Dimensional model may in fact need to be created. There are many problems associated with producing such a model. One of these is that not all angles may not have the same 'weight' – for example variations of hip rotation may be small compared to hip adduction and both may be large in value compared to pelvis sagittal rotation - 'lumping' each value together may water-down some values or over emphasis other values. A more nuanced model may be required. Unfortunately, further consideration of such a model remains beyond the scope of the current study.

Another consideration of this and future research highlighted by the author relates to the question of which kinematic values are used in the analysis. This study looked at peak excursion values and also the range of both extremes of movement (ROM). This latter measure was studied in order to gain further insight into movement patterns as sometimes the peak excursion values may only highlight certain characteristics of the movement patterns.

To elaborate on this further the reader is invited to consider 3 hypothetical subjects. Each of these has what a clinician may describe as having movement control issues but the movement fault occurs and different times and in different ways.

Subject 1 - Knee falls medially more than Subject 1 or 2 but only very briefly at point of max knee flexion.

Subject 2 – Knee falls medially in less than Subject 1 but for the full duration of the movement.

Subject 3 – Knee falls in less than Subject 1 but 'wobbles' into both valgus and varus repeatedly.

Using the conventional method of peak knee excursion, Subject 1 would be highlighted as having the more serious movement fault. Max deviation however may not necessarily be equal in value to ROM value or time spent in a deviated position._Sometimes what may be considered a poorer movement pattern may have an increase in knee valgus but with another subject this could manifest as a fluctuation between varus / valgus and in another it could manifest as a longer period in valgus but without an overall increase in the maximum value. This could be one of the major difficulties in defining a movement fault.

Ageberger at al 2010, found excellent correlation between visual frontal plane assessment of knee valgus against 2-D motion analysis but found this correlation was not forthcoming when compared against 3-D motion analysis. As the current discussion proceeds the reader is invited to consider the potential complications and 'watering down' of any findings, partly due to the scenario described above but even more significantly by the problems associated with analysing multiple-joint, multi-plane movement. Taken together these may go some way to explain why in the current study a pattern seemed to emerge between Fault and No Fault groups but there was insufficient power to record a statistically significant result.

It should also be considered that this study is not comparing the same movements. The small knee bend in the HLLMS was for example executed differently to the single leg squat and is obviously very different to the landing squat. Whilst one of the primary measures in this study was to compare a HLLMS medial knee deviation with the same deviation in the Military Functional Movements, an understanding of how the knee or hip deviate in other directions could be equally important for injury prevention. For example, an individual who has a low score on the HLLMS, i.e. they are considered by the HLLMS to have poor control, may also demonstrate poor control whilst doing other movement but the actual faults may occur differently in the kinetic chain. The need to consider the total ROM of a several joints simultaneously, in conjunction with the max and min excursions may provide a more complete reflection of potential faults and therefore the potential value of this screening tool.

Wilson et al (2018) who looked at the Criterion Validity of each individual movement of the standing aspects of the HLLMS found mixed results for both the HLLMS Knee Valgus and Pelvis Drop. Unlike this study which only looked at the left lower limb, Wilson et al (2018) looked at left and right. Interestingly, only the Right Leg HLLMS Knee Valgus movement criteria had a significant difference in the kinematics, namely peak knee valgus excursion. Between the Fault and No Fault groups there was no significant difference seen on the left. It was not stated whether hip kinematics were studied in relation to the HLLMS Knee Valgus criteria as was looked at by Ageberger et al (2010).

In addition to analysing single movement faults, this study proceeded to look at the HLLMS sub scores and the total scores. Positive correlation between HLLMS SKB sub-group and hip internal rotation, total ranges and ROM were found with surprisingly statistically significant results.

Recall that the HLLMS SKB test measures the following

Does the pelvis fail to stay level?

Does the knee fall into dynamic valgus?

Does the trunk lean forwards?

Does the pelvis tilt forwards?

The correlation tests found an 86% correlation between the Hip adduction max excursion value, p=0.006 on loaded lunge and a 72% correlation for an increase in knee rotational ROM on the lunge p=0.017. This suggests potential value in the SKB sub-score in predicting movement patterns at the knee and the hip with military specific movement patterns (taking-a-knee) and also with military specific characteristics of load carry.

Perhaps more important for the clinician is that it helps provide additional information and a record as to the causes of the knee valgus and internal rotation. As shown in Fig 6.1, albeit simplified to one plane, this result shows that either a hip adduction or pelvis drop will result in a knee valgus. Correcting this knee valgus therefore requires targeted correction and training – i.e. lumbo-pelvic control or hip mechanics. By completing the SKB total score, information on knee, pelvis and trunk potential faults can be gleaned and put to positive use by a clinician or sports therapist.

It also provides a tantalising suggestion as to the value of other individual aspects of the HLLMS. Losing a neutral pelvic tilt or trunk alignment for example has been shown to have links with injury in several sports (Cholewicki et al 2002) and the SKB test assesses both of these. Wilson and colleagues (2018) interestingly found excellent validity of both of these aspects in the SKB test. This therefore combined with the pattern of results seen in this study and discussed above, provides evidence that the SKB complete test has value in a clinical assessment.

Another interesting finding of this study was a clear correlation between the HLLMS Total score and the single HLLMS Knee Valgus Y / N score. A mean difference of 11 points was found. Although the knee valgus fault criteria is repeated in the SKB _ Rotation this replication would not account for the considerable increase in the overall score. In this way the SKB Knee Valgus could be said to have some predictive value of the HLLMS total score. Explained another way, if the HLLMS Total score proves to have value then the ability to control the knee remains central or links in some way several different aspects of movement control. At this stage it is not possible even to hypothesise what this relationship is but as explained above, the knee remains a useful ‘window’ to more proximal movement faults. Again, as stated above, the SKB total sub-score would arguably be a much more valuable test than a single knee valgus assessment as it provides information on 2 planes and of multiple joints.

In view of the difficulties this study found in establishing consistent links seen between single HLLMS movement faults and similar single plane Laboratory kinematics it would seem intuitive that correlations between laboratory single joint single plane findings would be even harder to establish. This was in fact the case and there were no further correlations found.

The reader should recall that the total score of the HLLMS, taken in its entirety identifies a complex collection of movement faults looking at several different movements. The faults identified could include:

Knee Dynamic Valgus

Hip Drop / Pelvis Fail to stay level

Pelvis anterior tilt

Pelvis posterior tilt

Thoracic forward lean

Thoracic backward lean

Thoracic side lean

Inability to rotate trunk whilst keeping the pelvis facing forwards.

Inability to flex the hip without posteriorly rotating the pelvis in sitting.

Inability to keep the pelvis ‘steady’ in a side lying position whilst raising the leg.

Inability to maintain fixed hip rotation whilst raising the leg in side lying.

Looking at the above it is now very clear that trying to find correlations between combined scores of the above, and for example a single plane single joint angle, would seem highly unlikely unless very distinct patterns between these exist.

It seems reasonable, for example, to surmise that a person who has a movement fault of a backward thoracic lean may not also ‘suffer’ from poor control at the hip or knee, or in fact that these would be consistent with different movements or different individuals.

The above discussion has focused on the primary aim of this paper which was to establish aspects of validity of the HLLMS measured against laboratory findings of functional military movements. i.e. HLLMS measured / evaluated against Nexus. The secondary discussion to follow provides some interesting insights into the potential value of the HLLMS total score.

One intriguing finding was that total scores of the HLLMS pre and post CFT revealed very clear changes. The difference in the mean of the groups before and after was approximately 3 points on the HLLMS. Whilst this gives very little direction as to how or what changes the HLLMS is able to assess it does suggest that there may be some value in completing the full test after all in order to establish patterns of movement faults in individuals.

Recall that the HLLMS sub group movements include the following:

Small knee bend

Small knee bend with rotation of the trunk

Sitting hip flexion whilst controlling the pelvis

Squat

Side lying leg raising with focus on pelvic control.

That changes to subtle control mechanisms were seen consistently in a group of Royal Marines after completing an 8 mile load carry with weapon certainly warrants further research into the potential value of the Total HLLMS score. This also suggests that there may be considerable value in testing subjects clinically after they have completed a CFT as only then do movement faults become apparent. Laboratory data on Pre and Post CFT was beyond the scope of this thesis and was not available for discussion of this paper but could form a basis for future evaluation and study of the above findings.

By contrast, there were no Changes identified between HLLMS total with and without load. Whilst this is a negative finding it actually provides further merit to the potential value of the HLLMS being done without the need to load the patient as there was no significant change in the test when done with load. As seen in the primary discussion above, a correlation between the SKB total score without load to a loaded lunge revealed an 86% correlation – this combined with the above negative finding suggests that a SKB test with load would be an unnecessary clinical endeavour.

Finally, Kinetics at the hip and knee were observed in the laboratory with and without load, with results showing a statistically significant increase in knee rotational force. With rotational force at the knee being a well-established mechanism of injury (Chapter 3), this finding whilst not surprising adds a layer of clinical significance to the primary findings in this study. That the SKB Knee valgus test may well provide predictive insight into valgus and internal rotation increases at the knee and hip and that the SKB Total score has predictive value in such movement faults under load that have been shown to have increased rotational forces at the knee under load provide a basis for ongoing use of the SKB test. That the HLLMS total score also seems sensitive to changes post arduous exercise in Royal Marines provides additional interest to this movement screen.

Finally, the author wishes to acknowledge several limitations of this study caused by technical difficulties in extracting meaningful data from the laboratory data collection. The author spent considerable time and energy attempting to extract data using the ScoRE and SARA methods for defining the hip and knee joint centres. As this employed software not previously familiar to The Institute of Motion Analysis and Research (IMAR) the end result was that it was necessary to revert to the Plug in Gait System. Fortunately this allowed for a substantial amount of data collection but there were issues around extracting some information due to differences in the marker placement and the set-up. A combination of this, as well as inherent difficulties with the movement patterns and the equipment carried by the subjects, meant that on average a third of the data was not extracted at the point or write-up despite significant efforts. The decision was made, partly on the advice of staff at IMAR, to conclude with the available data which was still substantial.

6.2 STUDY LIMITATIONS

The limitations of the Plug In Gait model of 3D motion analysis have been discussed in Chapter 3 and therefore caution should be taken with the results found in this study. A Type I Error is also known as a false positive and occurs when a researcher rejects a true null hypothesis. This is considered the more serious of errors and is why research is required to be robust and confidence levels are set at least 95%.

In this paper there were reported findings that did not achieve the 95% confidence and therefore there is a greater probability than acceptable that they occurred by chance. This has however been made clear throughout the discussion and taken as a group of findings and for the reasons made clear above, the author felt it appropriate to include them in this paper.

Other potential factors that could have introduced a Type 1 Error in this research could include using the incorrect statistical methods, statistical outliers, skewed data or operator bias. The correct statistical method has been used throughout and with consultation with a senior IMAR statistician.

Type 2 Error is where a researcher incorrectly rejects the alternative hypothesis or accepts the nul hypothesis. In this paper there are several opportunities for error due to errors of data collection, recording, calculations, data extraction and subject preparation.

Marker placement intra-rater reliability was confirmed through a known IMAR protocol where marker placement was checked at 6 week intervals. In this study however the author went on to use a modified marker placement set-up which was not independently verified for reliability. The marker placement used however is built on or added to the standard PiG method which was why the author was able to revert to PG data extraction when faced with repeated difficulties using the SCoRE and SARA functional model. The potential for error however was due to the fact that slightly less accuracy is required for marker placement on the functional model and it could be argued that the PiG markers were not placed with as much care as they might have been if the intention was to only use the PiG method.

The other major cause of a Type II error would be an incorrect or inconsistent recording of the HLLMS. This however was accounted for with a thorough two-day training session with a known SEM in using the HLLMS and intra-rater reliability was tested also on 20 test cases with a Reliabilty of >90%.

Data collection and extraction on the Vicon system is also prone to user-error. Subjects may not move consistently or produce a false reading by losing their balance etc. and for this reason protocol requires each trial to be repeated three times with the average value recorded.

This final point has been discussed at length above and the author believes that to prevent the possibility of a Type II error in future similar research that a different model may be required. As discussed above, this model could combine kinematic and kinetic data (separately) for the hip, knee and pelvis and thereby reflect more accurately a multi-joint 3-dimensional perspective

In summary, due to the fact that the results in this study were largely just outside the acceptable confidence level of 95% it would seem logical that the risk of a Type II error is greater in this study although an underlying Type I error could not be 100% discounted. The potential causes of a Type II error have been discussed above in detail, many of these have been considered and reasonably accounted for in the methodology. The one caveat to this being the underlying design of the study as potentially having insufficient sensitivity to detect movement faults in the 3-dimensional space thus increasing the likelihood of a Type II error.

CHAPTER 7

7.1 CONCLUSION

Muskulo-skeletal Injury Prevention remains one of the most sought after goals in military and sporting populations. There are many ways this can potentially be achieved such as having the appropriate equipment, modifying the volume of training, attaining appropriate fitness levels etc. There is increasing interest in movement control in injury prevention and how to measure and improve this remains a focus of many military and sporting institutions.

The Hip and Lower Limb Movement Screen (HLLMS) is one such method of screening and testing for movement faults. Many time-pressed clinicians may argue as to the value of completing a complex battery of tests such as the full HLLMS which with initial instruction and practice can require 30-45 minutes to complete. The question of whether choosing sub-sections or even single component parts of the HLLMS test would be more valuable remains an important practical consideration and one that this thesis has been able to provide valuable insight.

This study has been able to demonstrate consistent trends between HLLMS individual faults and potential harmful movement patterns when conducting military-type functional movements. In addition these findings have shown that these faults as seen with real-life movements are also reproduced under conditions of military load carriage.

This thesis has highlighted several questions around how future research may need to be applied. In particular the over-simplification of single-joint, single-plane movements in the laboratory may not reflect sufficiently the actual movement faults seen on the HLLMS as these present in a more complex 3-Dimensional way that which to-date does not have a suitable model to capture.

The clear conclusion of this thesis is that there appears significant utility in the use of measuring Knee Valgus and Pelvis movement faults and the Small Knee Bend sub-scale of the HLLMS. The HLLMS' ability to potentially predict movement faults at the hip and knee both unloaded and loaded are therefore recommended as an essential tool for the clinician working with Royal Marines or similar populations. As well as highlighting a potential movement dysfunction in the form of a score, the HLLMS provides details of where in the chain this fault arises and therefore where movement training is best placed to affect results and potentially reduce injury risk.

Finally, the Total Score of the HLLMS was also sensitive enough to show significant changes before and after a Combat Fitness Test. It remains unclear what aspects of the HLLMS were responsible for this and what value this may have in terms of clinical intervention but this thesis provides some interesting data that suggests completing the full HLLMS as part of a complete clinical assessment would provide meaningful information on movement control of several joints performing different and complex movement patterns.

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